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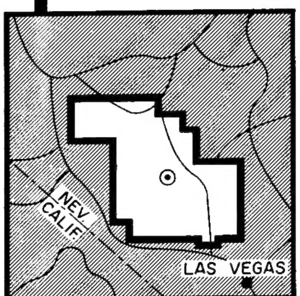
(WT-1811)

DEPARTMENT OF DEFENSE
U.S. ATOMIC ENERGY COMMISSION

Project DANNY BOY



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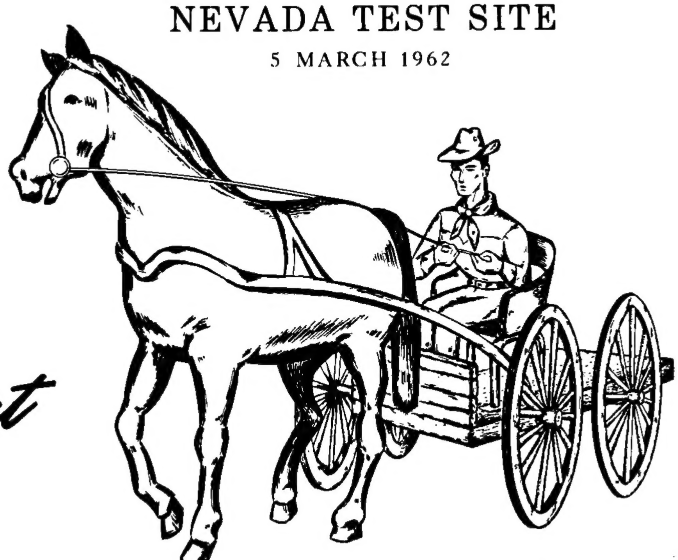

Final Report

Project 1.2

EARTH-MOTION MEASUREMENTS

L. F. Ingram

U. S. ARMY ENGINEER WATERWAYS EXPERIMENT STATION

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OPERATION DANNY BOY

POR-1811 (WT-1811)

PROJECT 1.2

EARTH-MOTION MEASUREMENTS

L. F. Ingram, Project Officer

U. S. Army Engineer Waterways
Experiment Station
Vicksburg, Mississippi

January 1964

This document is the author's report to the Chief, Defense Atomic Support Agency, of the results of experimentation sponsored by that agency during nuclear weapons effects testing. The results and findings in this report are those of the author and not necessarily those of the Department of Defense. Accordingly, reference to this material must credit the author. This report is the property of the Department of Defense, and as such, may be reclassified or withdrawn from circulation, as appropriate, by the Defense Atomic Support Agency.

ABSTRACT

The objective of Danny Boy Project 1.2 was to measure ground motion resulting from an underground nuclear detonation in basalt. This report presents and analyzes the measurements obtained from 31 vertically and horizontally oriented accelerometers and 3 vertically oriented velocity meters. The accelerometers and velocity meters were placed in the region extending horizontally from 3 to 610 meters from Surface Zero (SZ). All were placed near the surface (i.e. at depths of about 1/3 meter) except the accelerometer at the 3-meter station which was buried 18.3 meters deep.

Peak acceleration values were considerably less than anticipated. Because of low amplifier gain settings used in anticipation of higher signal levels, usable records were obtained on only 22 channels. However, because of the low acceleration levels, close-in measurements (i.e. close to SZ), which were of primary interest, were successfully made.

Peak acceleration attenuated approximately as slant range to the minus 5.6 power between 34 and 95 meters slant range, and as slant range to the minus 2.1 power between 95 and 300 meters slant range. Peak vertical acceleration

measured by a deeply buried gage at a horizontal range of 3 meters was approximately 5,700 g while the peak vertical acceleration at the surface 7.6 meters from SZ was 1,600 g.

Velocity of the compression wave, as calculated from arrival times read from the instrument records, ranged from 5.6 km/sec near the working point to 1.54 km/sec at a horizontal range of 305 meters. The low value at the greater distance indicates that the basalt at the test site was not uniform.

Peak particle velocity outside the crater ranged roughly from 8 m/sec at 50 meters horizontal range to 0.17 m/sec at 305 meters horizontal range. Peak particle velocity attenuated as slant range to the minus 2.1 power between 50 and 306 meters slant range.

Peak displacements outside the crater ranged from about 20 cm at 38.1 meters horizontal range to approximately 2 cm at 305 meters horizontal range.

PREFACE

The U. S. Army Engineer Waterways Experiment Station (WES) was requested to undertake the earth-motion study by the University of California Lawrence Radiation Laboratory (LRL) only a few weeks prior to Danny Boy. Originally, Stanford Research Institute (SRI) had proposed a similar project in this event; however, because of other commitments, SRI was unable to do this work. With the original SRI plan, and guidance from Sandia Corporation (SC) and LRL, an experimental plan was devised. Through procurement, and loan from other agencies and laboratories, sufficient transducers and cable were obtained which, when combined with existing WES equipment, provided 34 data channels.

The author wishes to acknowledge especially the cooperation and assistance of Mr. W. R. Perret, SC, who provided predictions and arranged for use of the SC spin-table facilities at the U. S. Atomic Energy Commission's Nevada Test Site (NTS) for accelerometer calibration. In addition, SC provided drawings of a velocity gage and loaned 150,000 ft of cable to WES.

Appreciation is expressed also to the U. S. Army

Ballistics Research Laboratories (BRL) for loan of cable and accelerometers, to the U. S. Naval Civil Engineering Laboratory (NCEL) for loan of accelerometers, and to SRI for advice and the loan of velocity meters.

The cooperation and assistance provided by LRL field support personnel are also acknowledged.

WES personnel participating in the field tests were Messrs. L. F. Ingram, Nuclear Weapons Effects Division, and F. P. Hanes, L. T. Watson, G. C. Downing, K. Daymond, C. E. Tompkins, S. R. Emerson, and G. H. Williams, Instrumentation Branch. Mr. Hanes was responsible for the instrumentation. Mr. J. K. Ingram assisted with data reduction and analysis. Mr. J. M. Pinkston helped with computational procedures. Mr. L. F. Ingram prepared this report.

This project was funded and supported at NTS by the Defense Atomic Support Agency.

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CHAPTER 1

INTRODUCTION

1.1 OBJECTIVES

The objectives of Danny Boy Project 1.2 were to measure and analyze the transient earth motion resulting from an underground nuclear explosion and thereby improve the understanding of cratering and earth-motion processes.

The Danny Boy device, with a yield of approximately 0.43 kt, was detonated at a depth of 33.5 meters in the basalt mesa of Area 18 of the U. S. Atomic Energy Commission's Nevada Test Site (NTS). It was anticipated that because of the shallow depth at which the device was buried, a crater would be formed.

× 3.28083 ft
109.907
= 110 ft

1.2 BACKGROUND

Because of the wide variance in physical properties of various soils and rock, it is not possible to predict with confidence certain effects of underground nuclear explosions. Results of the limited number of such shots fired heretofore do not provide sufficient basis for accurate prediction of earth-motion effects, especially in different soil types and for different depths of device burial. In addition, there

are presently no known analytical methods for predicting ground motion resulting from underground detonations in various soil and rock types and at various depths of burial. Therefore, it is essential to obtain all possible empirical information with which to verify (or refute) theoretical considerations and to add to the practical knowledge that will be valuable in developing peaceful uses of atomic energy in the field of explosive excavation. The Danny Boy experiment provided test conditions worthy of investigation.

CHAPTER 2

PROCEDURE

2.1 PLAN OF EXPERIMENT

The experiment was designed to measure vertical ground motion both on and beneath the surface in the crater zone, and to provide additional such measurements on the surface at ranges extending well into the elastic region. The symmetry of the wave was to be determined by placement of gages on three azimuths from Surface Zero (SZ).

2.1.1 Gage Layout. Table 2.1 gives the locations of instruments and the types of measurements made. All instrument stations were located along the main gage line (which had a true bearing of approximately 135 degrees from SZ) except the 152-meter stations located on relative bearings of 90 degrees left and right from the gage line. The use of three azimuths for the 152-meter stations was intended to provide data on the symmetry of the compression wave.

2.1.2 Set-Range Predictions. It was necessary that predictions of acceleration amplitude as a function of range from SZ be made so that appropriate instrumentation could be selected. The predicted accelerations also dictated the

sensitivity of the recording equipment. For this experiment the instrument set ranges were predicted based on the Project Gnome test results (Reference 1) inasmuch as these data appeared to be the best available for prediction purposes. It was believed that, because of more nearly matched physical characteristics of halite (the Gnome test medium) and basalt, the Gnome results would be more applicable than results of previous underground detonations at NTS in the Oak Springs tuff (Reference 2). The following tabulation shows that the acoustical impedance ($\rho \times c$) match of basalt and halite is in closer agreement than that of basalt and tuff.

Material	Density, ρ	Seismic Velocity, c
	gm/cm^3	km/sec
Basalt	2.7	5.3
Halite	2.3	4.1
Tuff	1.9	2.0

In materials of high acoustical impedance, stress (and acceleration) waves are less rapidly attenuated with distances than in lower impedance media; therefore, the peak acceleration-distance relation for Danny Boy was expected

to be in fair agreement with that determined for Project Gnome.

Figure 2.1 shows the predicted free-field acceleration scaled from Gnome results. Additional allowances in amplifier gain settings were made to account for the expected increase in acceleration amplitude caused by the ground surface effect. The increased amplitude is a result of the compression wave reflecting as a tensile wave at the free surface.

2.2 INSTRUMENTATION

2.2.1 Transducers. Of the 31 accelerometers used in this study, 11 were Wiancko variable-inductance type, 2 were Consolidated Electrodynamics Corporation (CEC) strain-gage type, and the remaining 18 were Statham strain-gage type. All of these instruments employ a seismic mass and are fluid-damped. The damping ratio of all gages was specified by the makers to be approximately 0.65 times critical. Since only static calibrations were made, this was not verified.

The three velocity meters used to measure vertical particle velocity were designed by the Stanford Research

Institute (SRI) and employ a linear differential transformer as the sensing element. A solenoid is provided in the gage to hold the transformer core in a raised position. The core is released and allowed to fall under the influence of gravity in a highly viscous silicone fluid. The core attains an approximately constant velocity equivalent to 32.2 ft/sec for a fall time of a few seconds. Relative motion of the transformer coils and falling core is proportional to the velocity of the gage core. Core release is synchronized in such a manner that the ground shock arrives at the gage while the core is falling at a uniform velocity and sufficient fall time remains to measure the motions of interest. This gage is described in detail in Reference 3.

Figure 2.2 shows the various transducers used in this study.

2.2.2 Calibration of Transducers. All accelerometers with a range greater than 5 g[1] were calibrated statically on the Sandia spin table at NTS, and with the exception of the 5,000-g and 1,500-g units, were calibrated from 20 to 50 percent in excess of their rated capacities to allow for

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[1] 1 g = 9.8 m/sec^2.

possible overranging. The maximum capacity of the spin table was 1,000 g.

The 5-g units were calibrated in the earth's gravitational field by the 2-g turnover method. This was done at the test site after the accelerometers were mounted in the canisters.

All calibrations were made with the proper cable lengths attached to the gages. Calibration resistors were selected for each accelerometer which, when shunted across one arm of the transducer bridge circuit, produced an unbalance signal step equivalent to a known acceleration level.

Some difficulty arose when the high output of the Wiancko accelerometers overloaded the amplifiers and caused nonlinear galvanometer deflection. This was overcome by removing the tube of the first amplifier stage and capacity-coupling to the next stage.

The velocity meters were calibrated in place by dropping the core and recording the gage output during the core's fall. Since the sensitivity of this gage is related to the viscosity of the silicone fluid, it is affected also by temperature changes. Therefore, to ensure an accurate

calibration, the core drop was made a few seconds before shot time. The core was then raised and dropped again to record ground motion resulting from the shot.

2.2.3 Electronics and Recording Systems. The recording equipment was contained in an instrument van acquired from the U. S. Army Engineer Research and Development Laboratory (ERDL). The van contained 24 CEC, 20-kc/sec carrier, amplifier channels; 48 CEC, 3-kc/sec (System D) carrier, amplifier channels; 72 CEC galvanometer-recording channels (two 36-channel recorders); two 14-channel, Ampex FR-100, magnetic-tape recording systems (FM mode); and 16 Miller (now CEC) oscilloscope-recorder channels.

It was planned initially to use several channels of the 20-kc/sec system with the close-in accelerometers (i.e. those closest to SZ) to take advantage of the higher frequency response of this system; however, because of difficulties encountered during calibration with long cable lengths (5,600 feet), this system was abandoned. Therefore, all gages were used with System D (3-kc/sec), and the galvanometer oscillographs were used for recording.

Galvanometers with several different flat frequency ranges were used in such a manner that the limiting system

component for high-frequency response was the amplifier (flat response to about 600 cps) for the close-in gages and the galvanometer (flat response to 350 cps) for the more remote gage stations.

The magnetic-tape system was used to provide backup for 22 selected channels.

2.3 FIELD OPERATIONS

Conditions at the project site were far from ideal in that work was hampered by cold weather, snow, mud, and rough terrain along the main gage line.

2.3.1 Recording Van Shelter. An aboveground, timber bunker, protected on the top and front side by sandbags, was used as a van shelter (Figure 2.3). The shelter was located one mile from SZ, and it was planned that the shelter would be upwind at shot time.

2.3.2 Instrument Cables. Instrument cables were run unprotected on the ground surface to within about 230 meters of SZ. From that point to 45 meters from SZ, they were protected by sections of steel pipe cut in half, which were in turn covered with sandbags. From this location to the gage station closest to SZ (3 meters), the cables were not

protected but were suspended in loose loops from a wire drawn taut between the Edgerton, Germeshausen and Grier (EG&G) photo targets. These precautions near SZ were designed to allow sufficient slack in the cables to keep them intact for as long a period of time as possible, especially in the region of the crater and plume. Figure 2.4 shows a view of the cables looking toward SZ (only the white cables belong to Project 1.2).

Figure 2.5 shows the special precautions taken in cable placement for the accelerometer buried 18.3 meters deep at the 3.05-meter station. The cable grouted into the ground was protected by placing it inside a piece of garden hose. (The instrument hole is in the center of the concrete block at the near corner of the building in Figure 2.5.) This arrangement permitted movement of the cable within the hose and thus prolonged time until cable failure. The electrical cable (white cable in Figure 2.5) was tied to the support wire with short pieces of solder to provide a weak link for release of the cable when the ground started to move. (The loop shown on the ground was retied before the shot.)

2.3.3 Gage Installation. All accelerometers were mounted in canisters; the velocity meters were

self-contained. The accelerometer canisters at the 7.62-, 38.1-, and 45.7-meter stations were fastened to 4-by-4-in. EG&G photo target posts which were set in concrete. Figure 2.6 shows details of this installation. The remainder of the instruments were grouted into 1-ft-deep holes in masses of concrete that had been poured in holes excavated in the ground. Figures 2.7 and 2.8 show installation holes for accelerometer canister and velocity meter, respectively, prior to installation and final grouting. The grout, made by Concrete Division personnel of the U. S. Army Engineer Waterways Experiment Station (WES), utilized a fast-setting, high-strength cement.

2.3.4 Power and Instrument Control. Primary and standby power were provided by separate 50-kva diesel generators. In the event of primary power failure, switchgear provided by WES was capable of transferring the load rapidly from the primary generator to the standby unit without excessive transient power surge.

Two EG&G radio-relay timing signals were used at shot time to synchronize recording instrumentation. A minus-one-minute signal started a programmer in the instrument van. The programmer controlled starting, stopping, and speed

changing of oscillograph cameras and tape-transport mechanisms, application of calibration signals, etc. A minus-one-second EG&G signal was used to release the cores in the velocity meters.

2.3.5 Instrument-Record Recovery. A two-man team returned by helicopter to the van at about H+2 hours to recover the instrument records. Because of favorable winds there was no radioactive contamination in the shelter area as indicated by the zero-dose reading observed on dosimeters placed inside the van prior to the shot.

TABLE 2.1 PLACEMENT, IDENTIFICATION, AND CALIBRATION OF INSTRUMENTS

All instruments were nominally at ground surface except the 3.05-meter accelerometer which was buried 18.3 meters deep. V, vertical component; R, horizontal component oriented radially from SZ; T, horizontal component normal (transverse) to radial component.

Gage No.	Horizontal Range from SZ	Azimuth	Orientation	Make	Capacity	Recording Galvanometer Sensitivity	
	meters	degrees			g	g/in.	m/sec/in.
1-AV	3.05	135	V	Statham	5,000	10,950	--
2-AV	7.62	135	V	Statham	5,000	8,850	--
1-AH	38.1	135	R	Statham	1,500	1,710	--
3-AV	38.1	135	V	Statham	1,500	1,615	--
4-AV	45.7	135	V	Statham	1,500	1,890	--
1-VM	45.7	135	V	SRI	Velocity meter	--	19.61
2-AH	54.9	135	R	Statham	500	830	--
5-AV	54.9	135	V	Statham	500	445	--
3-AH	73.2	135	R	Statham	300	416	--
6-AV	73.2	135	V	Statham	300	442	--
4-AH	73.2	135	T	Statham	200	188	--
2-VM	73.2	135	V	SRI	Velocity meter	--	17.08
5-AH	91.4	135	R	Statham	200	180	--
7-AV	91.4	135	V	CEC	150	108	--
6-AH	91.4	135	T	CEC	150	108	--
7-AH	152	135	R	Wiancko	100	89.8	--
8-AV	152	135	V	Wiancko	100	85.4	--
8-AH	152	135	T	Wiancko	50	110	--
9-AH	152	45	R	Wiancko	100	60.2	--
9-AV	152	45	V	Wiancko	50	25.6	--
10-AH	152	45	T	Wiancko	25	16.7	--
11-AH	152	225	R	Wiancko	100	98.5	--
10-AV	152	225	V	Wiancko	100	99	--
12-AH	152	225	T	Wiancko	50	24.2	--
3-VM	152	135	V	SRI	Velocity meter	--	25.80
13-AH	228	135	R	Wiancko[a]	25	12.6	--
11-AV	228	135	V	Statham	20	11.4	--
14-AH	228	135	T	Wiancko[a]	10	None	--
15-AH	305	135	R	Statham	5	1.05	--
12-AV	305	135	V	Statham	5	1.26	--
16-AH	305	135	T	Statham	5	1.71	--
17-AH	610	135	R	Statham	5	4.37	--
13-AV	610	135	V	Statham	5	1.70	--
18-AH	610	135	T	Statham	5	1.79	--

[a] Gages were inoperative at shot time.

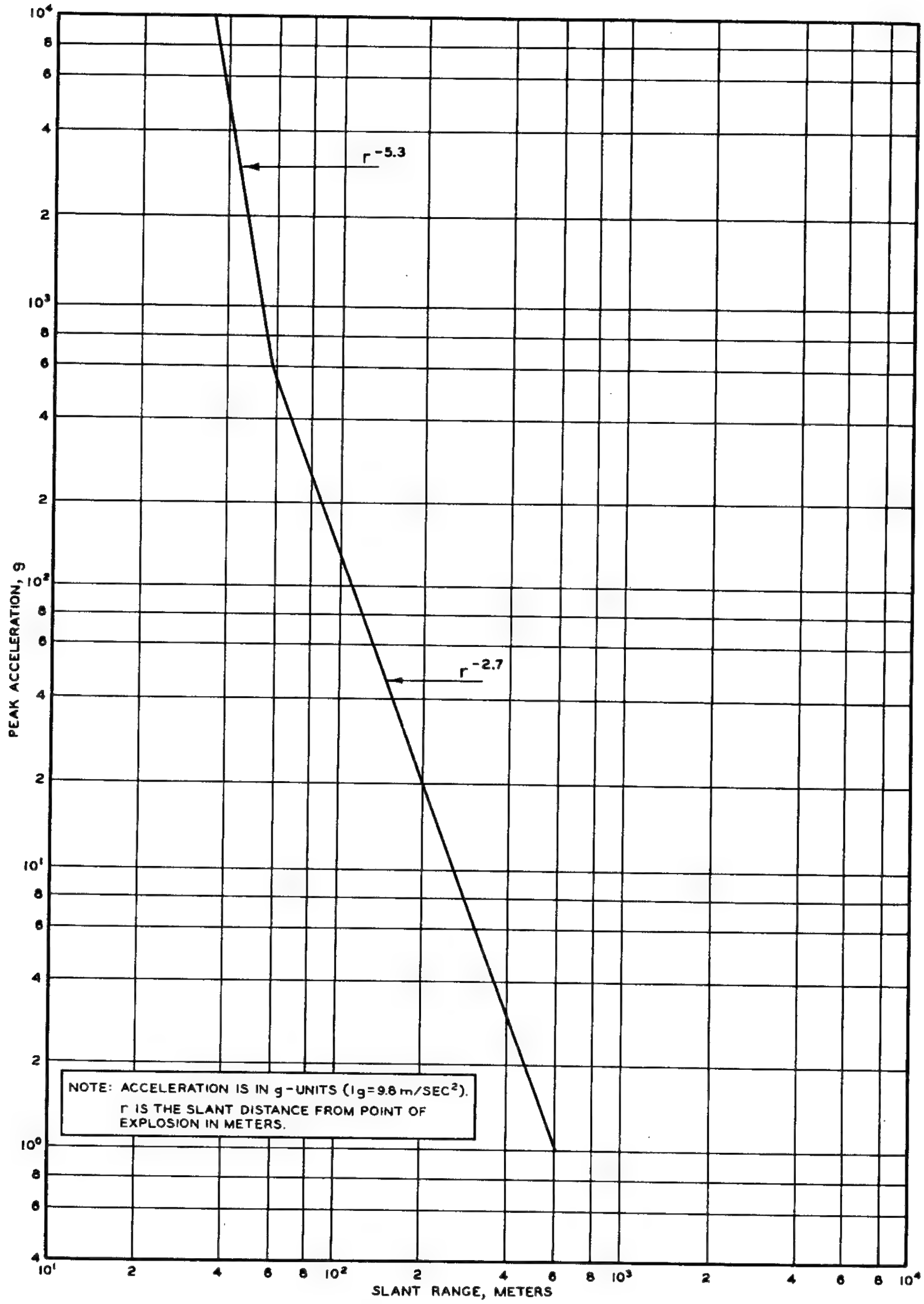


Figure 2.1 Predicted acceleration (Reference 1).

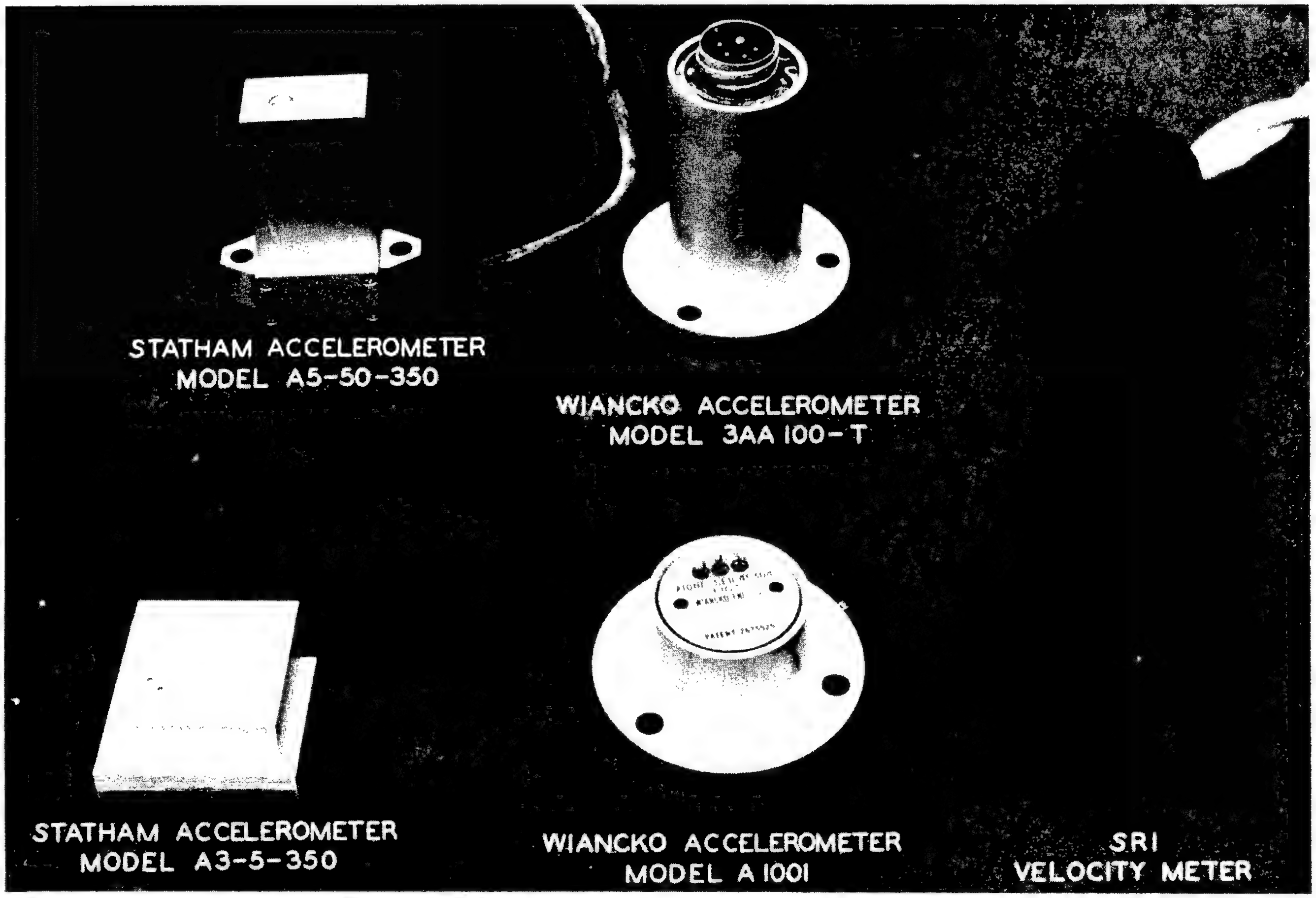


Figure 2.2 Transducers.

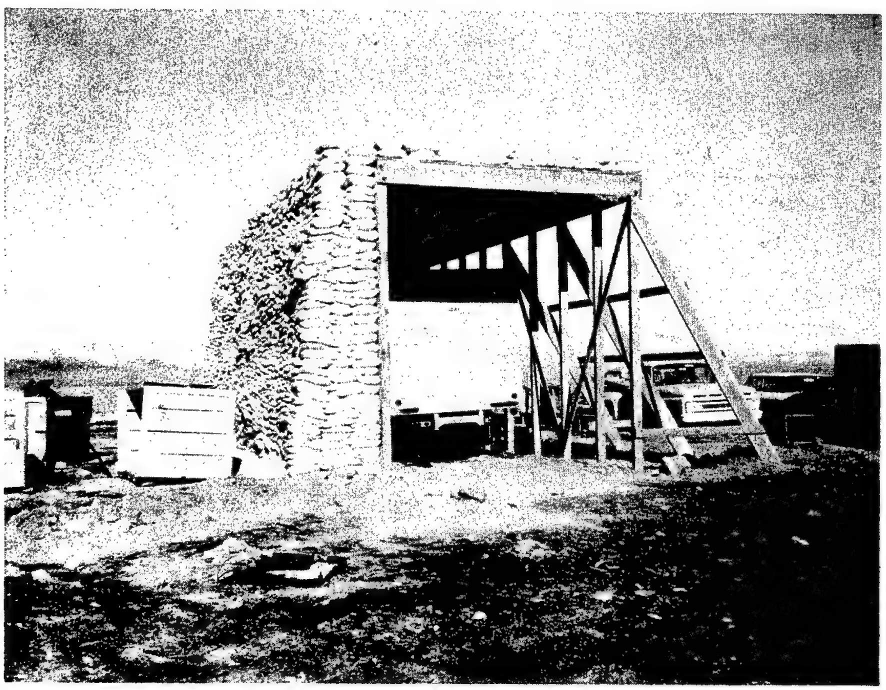


Figure 2.3 Project 1.2 instrument van shelter.

Figure 2.4 View toward SZ showing instrument cables.

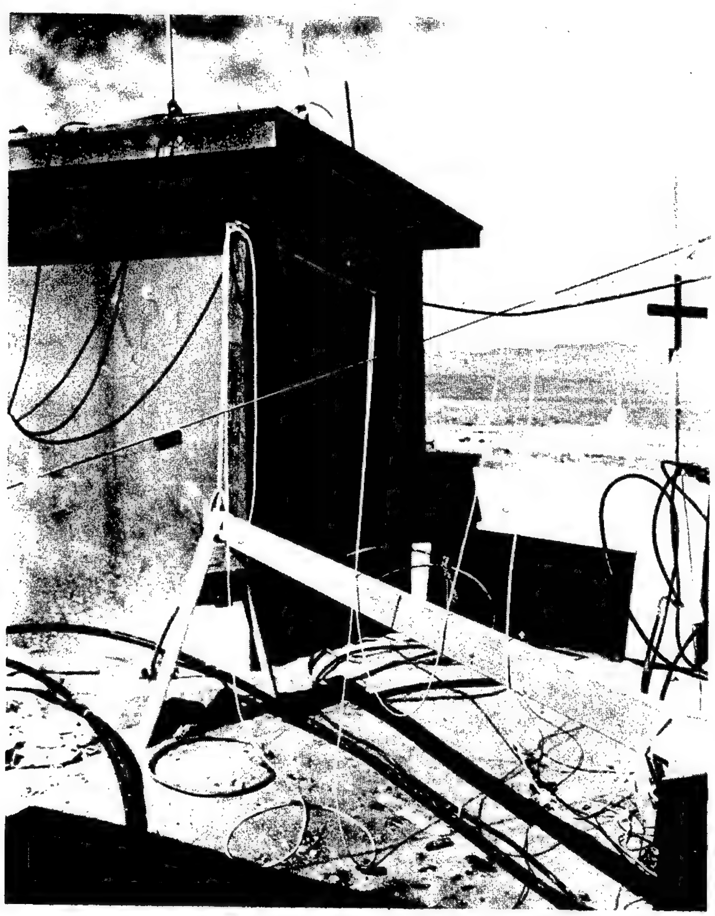


Figure 2.5 Cabling for buried accelerometer at 3.05-meter station.

Figure 2.6 Accelerometer canister attached to EG&G photo target post.

Figure 2.7 Accelerometer canister installation.

Figure 2.8 Velocity meter installation.

CHAPTER 3

RESULTS

3.1 INSTRUMENT PERFORMANCE

The programmed control functions were perfect, and records were obtained from both CEC and magnetic-tape recorders. Playback of the magnetic tapes revealed distortion caused by improper reference phasing in the compound modulation system. The distortion, which could not be removed, rendered the tapes unusable.

Anomalous ground motions were not present, i.e. initial movement was always away from SZ on radially oriented instruments and upward on vertically oriented instruments.

The radial and transverse accelerometers at the 228-meter station developed circuit trouble prior to shot time and were inoperative.

Synchronization of the velocity-meter core releases was such that the shock pulse arrived very nearly in the middle of the core-fall period. The two velocity meters closest to SZ generated usable signals but each had apparent base-line shifts occurring at later times which could not be corrected; the net result was reliable values from initiation

to peak only. The velocity meter at the 152-meter station apparently did not sense a measurable velocity.

A disturbance at zero time was recorded on each signal trace; however, the length of this disturbance was not sufficient to interfere with the motion inputs. Figure 3.1 shows a composite of several of the oscillograph records reduced by approximately one-third original size. The first disturbance visible in Figure 3.1, occurring simultaneously on all traces, is attributed to the electromagnetic (EM) pulse which decays within about 2 msec on most traces. The rate at which the EM pulse decays on these records appears to be related to the damping characteristics of the galvanometers. It was noted that the fluid-damped galvanometers, which were used at the stations closest to SZ, recovered more rapidly than the magnetically damped galvanometers.

3.2 DATA REDUCTION AND INTERPRETATION

It is apparent from the oscillograph records (Figure 3.1) that arrival times and amplitude values were difficult to scale precisely on some traces and impossible to obtain on others. Nevertheless, all readable traces were read

using a commercial light table equipped with optical magnification and circuitry for digitizing the data. The WES GE-225 digital computer was used to process the data (Reference 4). Two different methods were used in the double integration routines. The first method was simply uncorrected double integration of the as-read data points. All traces were not double integrated because of the extremely low amplitude levels. The second method provided for a uniform base-line shift in the acceleration record to force the velocity to zero at the time at which all motion was considered to have ceased. All accelerometer records which were double integrated received the uniform base-line correction with the exception of data from gages 1-AH and 3-AV.

Table 3.1 presents results of the ground-motion measurements.

3.3 ARRIVAL TIMES

Figure 3.2 is a plot of arrival time (T_a) of the first disturbance detected on the oscillograph traces. Figure 3.3 shows a plot of average seismic velocities calculated from arrival times. The average compression-wave velocity for the deeply buried accelerometer, 1-AV, located only 15.6

meters (slant range) from the device, was 5.64 km/sec. This value agrees with seismic velocity values obtained in the laboratory on small samples of fairly solid basalt. However, the seismic velocity at the 305-meter station was only 1.54 km/sec. It is apparent from the low velocity values at the greater distances from SZ that the basalt at the test site is not uniform.

It was difficult to determine arrival times precisely at the 152-meter station because of the very low trace amplitude; therefore, the symmetrical expansion of the ground wave is uncertain. Nevertheless, the spread in arrival time values at this station is not excessive, and it is concluded that the seismic velocity was fairly uniform along the three instrumented radii.

3.4 ACCELERATION

Since the accelerations were not nearly as high as anticipated, readable values were obtained from only 19 measurements, four of which were peak values only. Except for the measurements at the 305-meter station, the best (largest trace amplitude) records were obtained from gages placed close to the explosion. This can be seen in the

oscillograph record (Figure 3.1). (The 305-meter traces are not shown in the figure because of the large time scale required.) A complete tabulation of parameters determined from the measurements is given in Table 3.1.

Figure 3.4 shows the acceleration-time histories obtained from traces with amplitudes large enough to read with reasonable accuracy on an optical reader-digitizer having a resolution of 1,000 data points per inch. These histories represent the raw data as read from the oscillograms and replotted to an enlarged scale, and are included herein for convenience in studying the uncorrected (or unadjusted) data. Also included in Figure 3.4 are the velocity and displacement histories obtained from successive integrations of the basic acceleration records. The effect of the base-line corrections can be seen by comparing the traces in Figure 3.4 with those in Figure 3.5, which shows the histories after application of the correction procedure described in Section 3.2.

The peak acceleration values given in Table 3.1 are plotted in Figure 3.6 for comparison with prediction accelerations (Reference 1) and other nuclear test data (Reference 2). Where base-line corrections were used in the

integration routine, the values plotted are the adjusted peak values. Peak acceleration was found to attenuate approximately as slant range to the minus 5.6 power between 34 and 95 meters slant range, and as slant range to the minus 2.1 power between 95 and 300 meters slant range.

3.5 PARTICLE VELOCITY

Readable velocity measurements were obtained with the SRI vertical velocity gages placed at the 45.7- and 73.2-meter stations (gages 1-VM and 2-VM, respectively). The third instrument (3-VM) did not respond to the low velocity level at 152 meters horizontal range. Peak particle velocities obtained directly from the velocity gages and from the first integration of the better acceleration histories are plotted against slant range in Figure 3.7. Peak particle velocity outside the crater ranged roughly from 8 m/sec at 50 meters horizontal range to 0.17 m/sec at 305 meters horizontal range. Peak particle velocity was found to attenuate approximately as slant range to the minus 2.1 power between 50 and 306 meters slant range.

3.6 DISPLACEMENT

Peak and final displacements obtained by double

integration of acceleration histories obtained outside the crater are shown in Figures 3.8 and 3.9, respectively. Peak values were not obtained for gages which moved with the plume of ground because of early cable failure. In addition, relatively high-range accelerometers placed at these stations did not allow accurate position and velocity measurements at low velocity levels. Nevertheless, the early motion histories for the gages (1-AV, 2-AV, 3-AV, 1-AH) located where gross motion occurred (in the crater and plume) are shown in Figure 3.4.

It was possible to compare displacement results with only one independent observation. The vertical accelerometer (3-AV) at 38.1 meters horizontal range was attached to an EG&G photo target post (see Figure 2.6). Figure 3.10 compares the EG&G results obtained from analysis of motion picture films (Reference 5) and the WES displacement data obtained by means of twofold integration of the 3-AV accelerometer record. The values coincide at about 50 msec. It is suspected that the accuracy of the ground-motion measurements determined from the photographs is not good for small motions (i.e. in the early time history); therefore, the independent observations complement each other. The

arrival time and early history determined from the accelerometer record are probably more reliable than those obtained from the photographs for the initial motion.

TABLE 3.1 TABULATED RESULTS

Gage No.	Horizontal Range from SZ	Orientation	Slant Range from Center of Charge	Arrival Time	Average Seismic Velocity	Peak Acceleration		Peak Particle Velocity	Peak Displacement	Final Displacement
	meters		meters	msec	m/sec	g	m/sec^2	m/sec	cm	cm
1-AV	3.05	Vertical	15.6	2.77	5,640	5,694[a]	55,800[a]	--	--	--
2-AV	7.62	Vertical	34.4	9.42	3,656	1,600	15,700	--	--	--
3-AV	38.1	Vertical	49.4	18.2	2,715	226	2,220	6.97	19.0	19.0
1-AH	38.1	Horizontal(R)	49.4	18.2	2,715	180	1,760	7.34	20.6	20.6
4-AV	45.7	Vertical	56.4	20.6	2,740	300	2,940	8.35	13.4	13.4
1-VM	45.7	Vertical	56.4	21.5	2,620	--	--	5.23	--	--
5-AV	54.9	Vertical	64.1	24.2	2,650	38.6	378	--	--	--
2-AH	54.9	Horizontal(R)	64.1	27.2	2,360	47.4	464	--	--	--
3-AH	73.2	Horizontal(R)	80.2	44.2	1,820	14.4[b]	141[b]	--	--	--
4-AH	73.2	Horizontal(T)	80.2	44.4	1,805	8.26[b]	81.0[b]	--	--	--
2-VM	73.2	Vertical	80.2	46.0	1,740	--	--	2.35	--	--
7-AV	91.4	Vertical	95.7	45.8	2,080	7.29[b]	71.5[b]	2.56	5.00	2.00
5-AH	91.4	Horizontal(R)	95.7	44.9	2,130	5.40	53.0	--	--	--
6-AH	91.4	Horizontal(T)	95.7	44.8	2,140	3.71	36.4	1.79	2.00	2.00
9-AV	152	Vertical(R-90°)	156	89.9	1,740	3.90	38.2	0.644	4.20	4.20
7-AH	152	Horizontal(R)	156	90.0[a]	1,405[a]	3.21[b]	31.4[b]	--	--	--
9-AH	152	Horizontal(R-90°)R	156	85.0	1,885	6.02[b]	59.0[b]	--	--	--
10-AH	152	Horizontal(R-90°)T	156	90.7	1,720	0.670	6.57	0.637	--	--
11-AH	152	Horizontal(L-90°)R	156	88.2	1,770	--	--	--	--	--
12-AV	305	Vertical	306	198	1,545	0.470	4.58	0.663	--	--
15-AH	305	Horizontal(R)	306	200	1,530	0.296	2.90	0.169	2.10	0.800
16-AH	305	Horizontal(T)	306	199	1,538	0.393	3.85	0.171	2.60	0.900

[a] Questionable value.
[b] Peak value only.

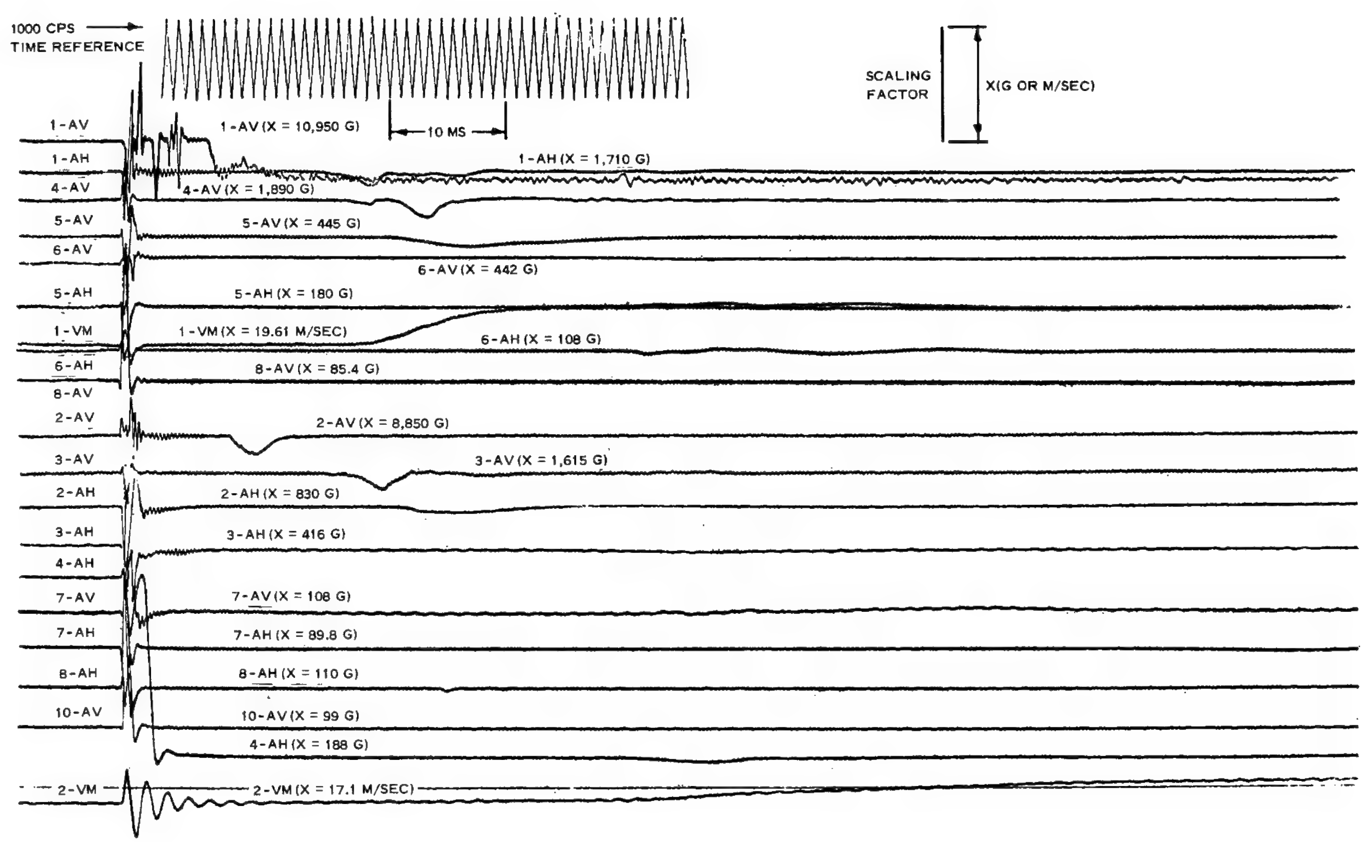


Figure 3.1 Oscillograph traces.

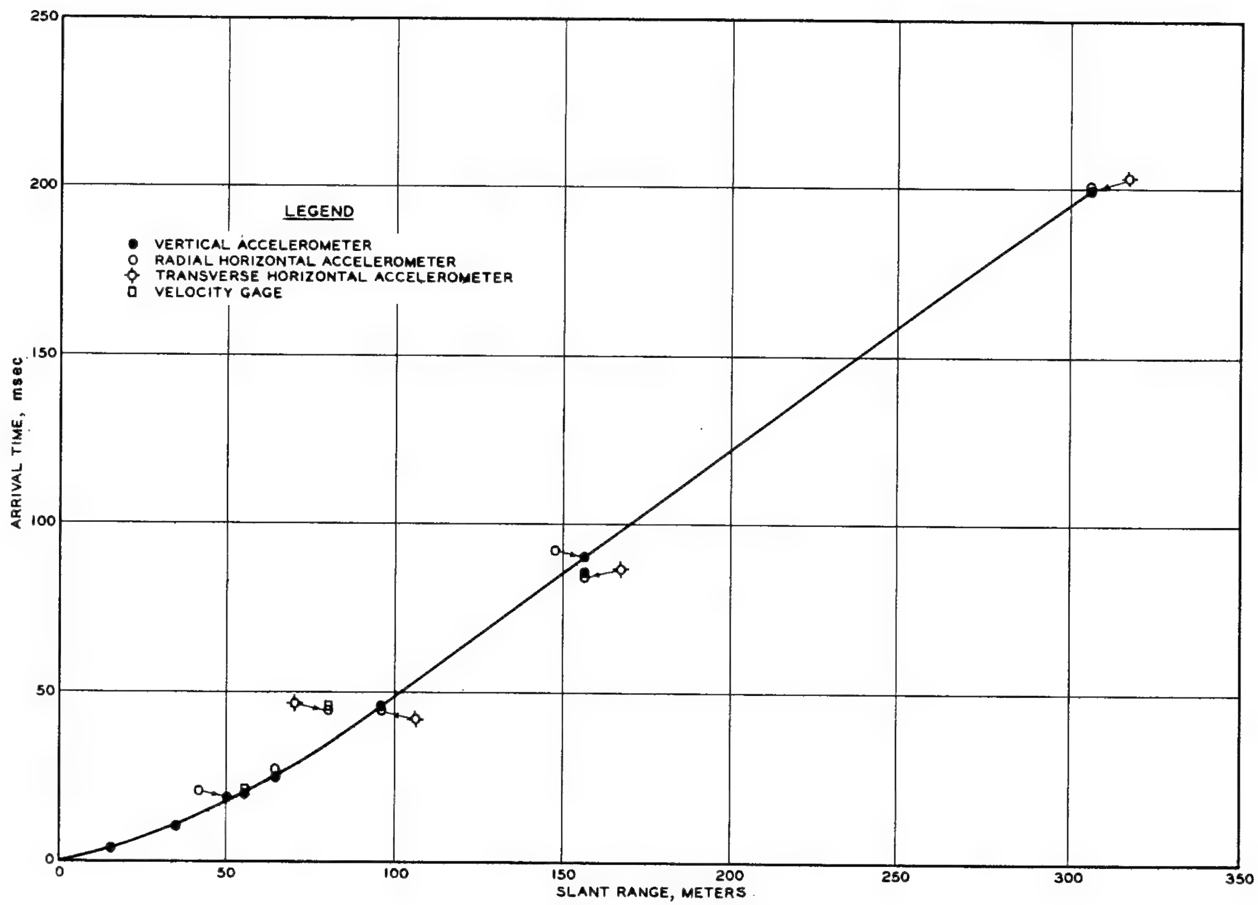


Figure 3.2 Arrival time (first disturbance) versus slant range.

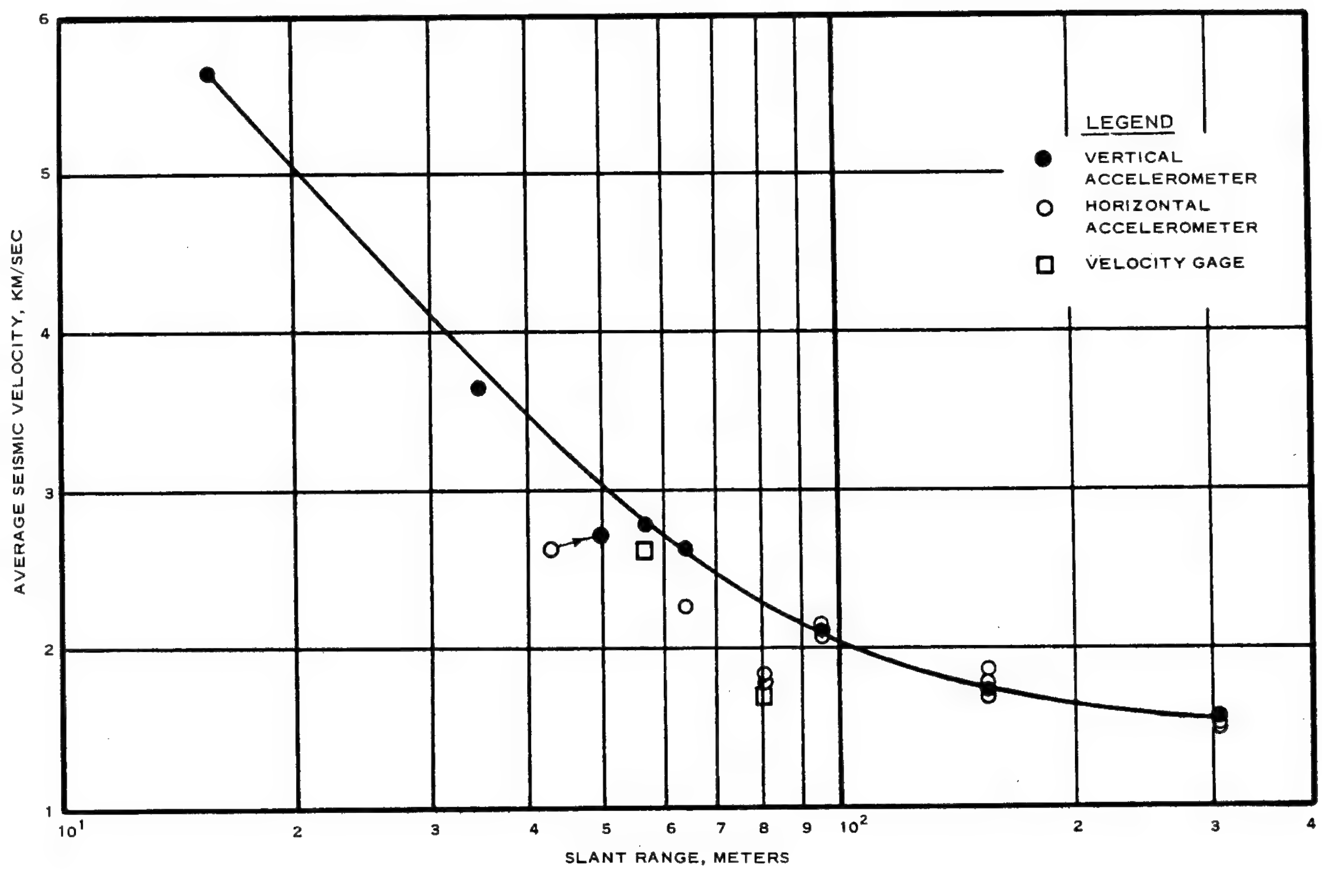


Figure 3.3 Average seismic velocity versus slant range.

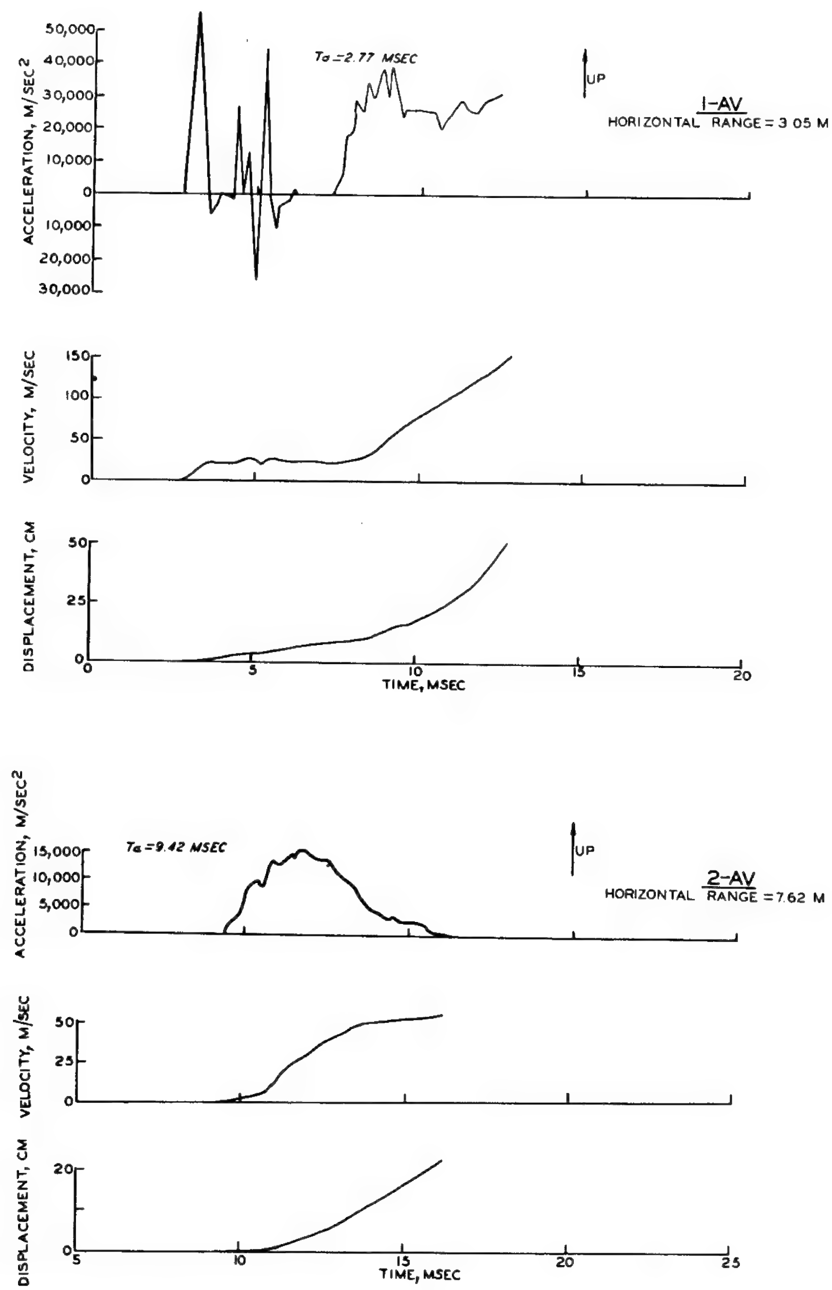
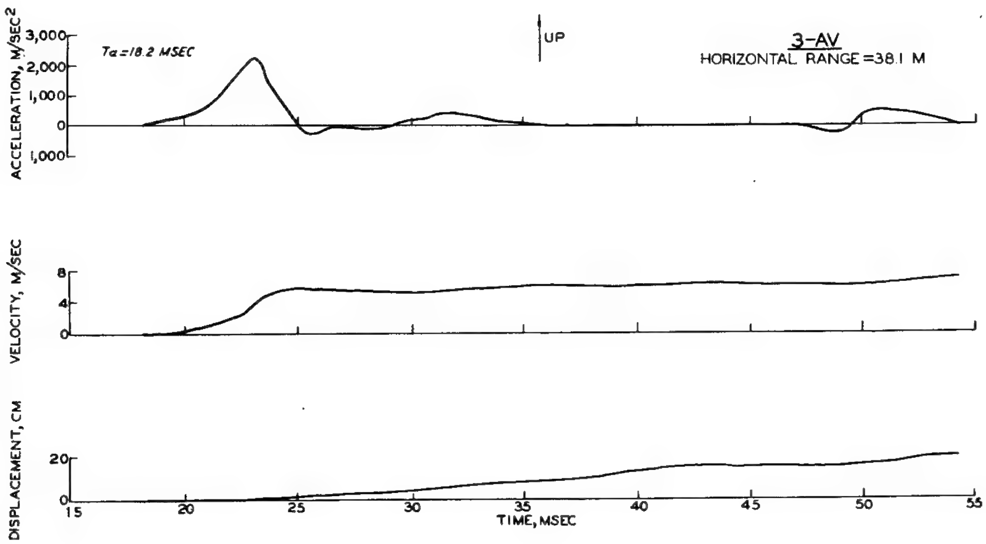


Figure 3.4 Uncorrected acceleration histories with twofold integrations (1 of 7 pages).



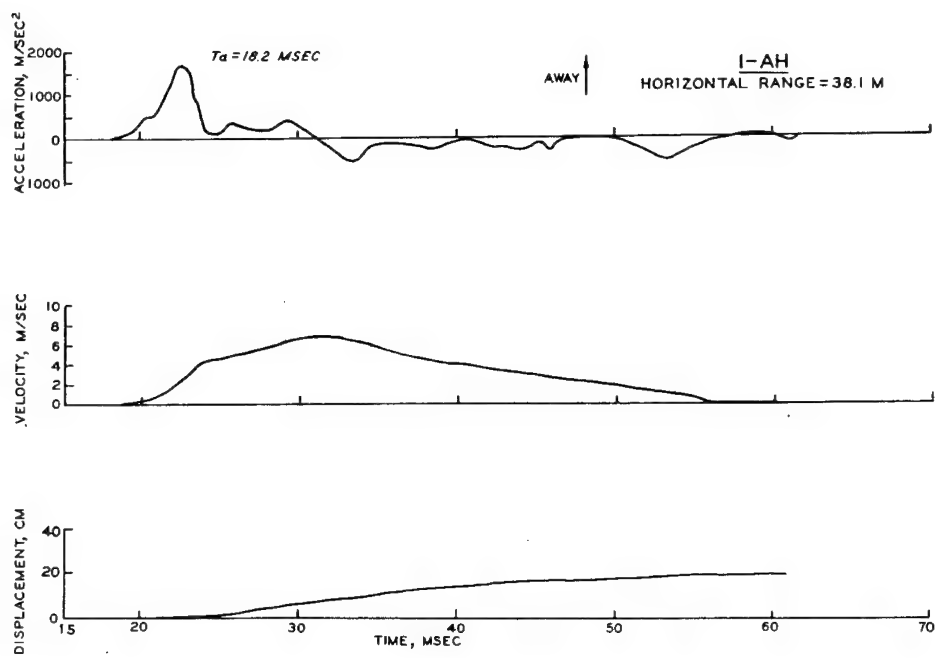
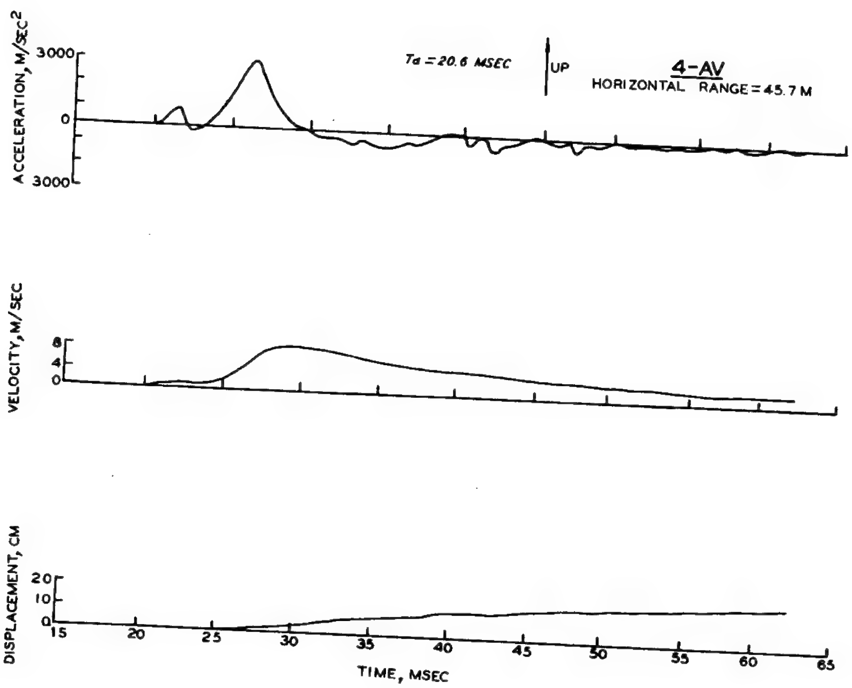


Figure 3.4 (2 of 7 pages)



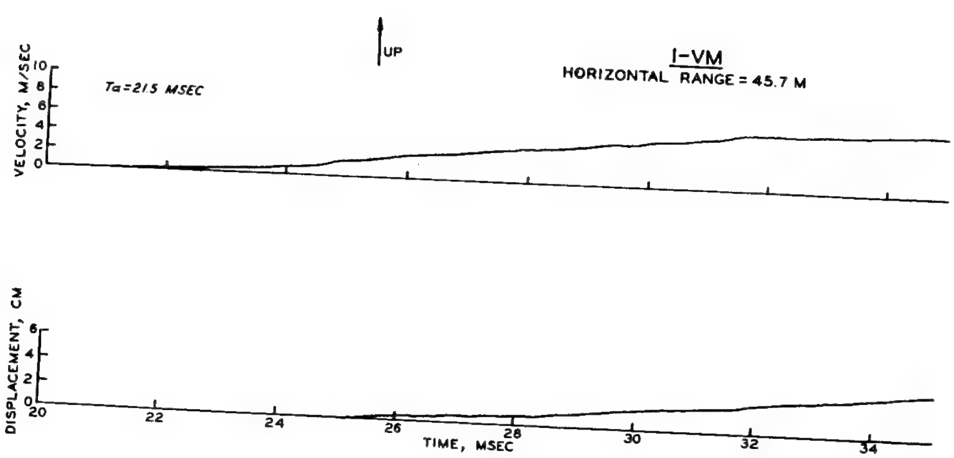


Figure 3.4 (3 of 7 pages)

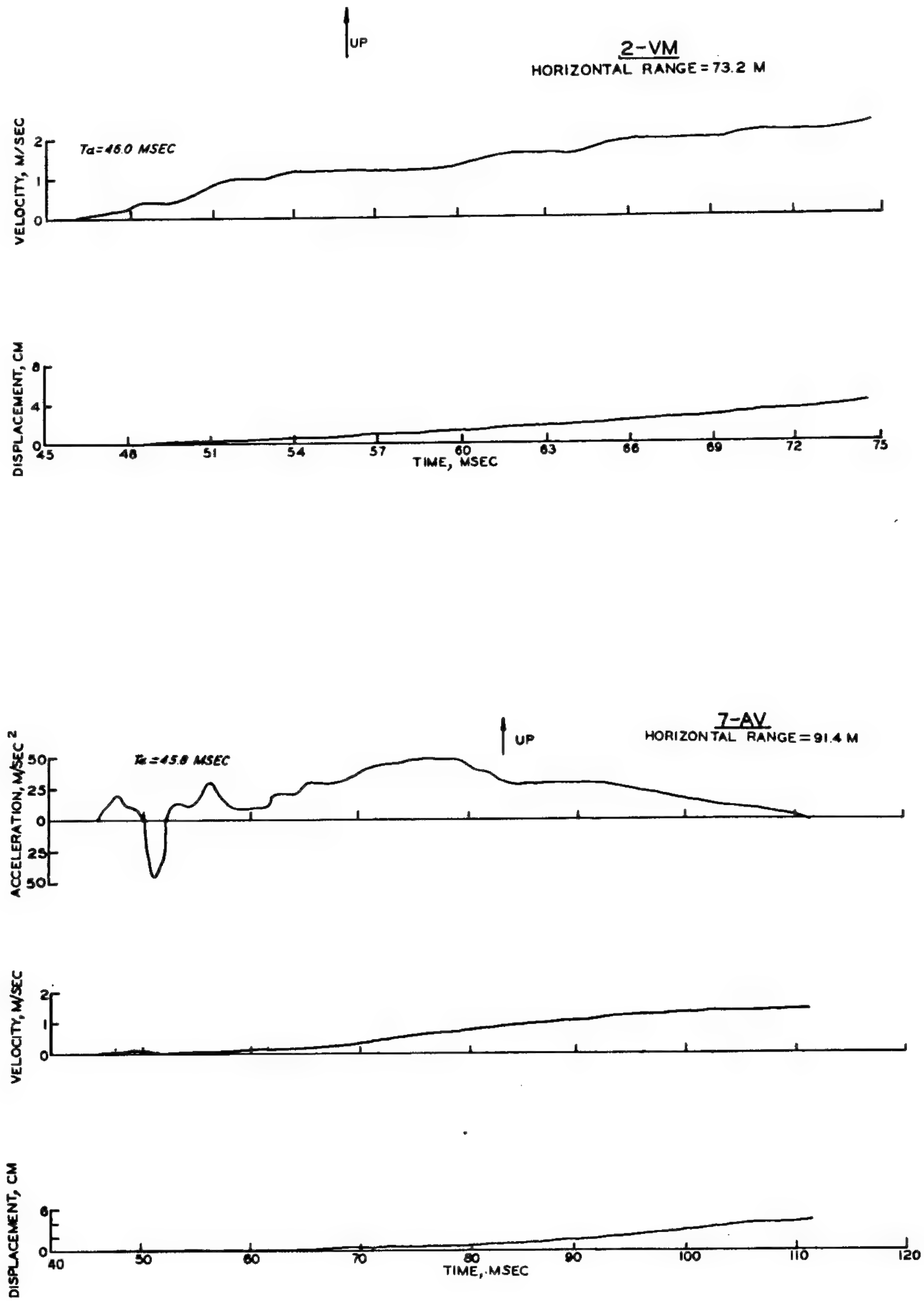
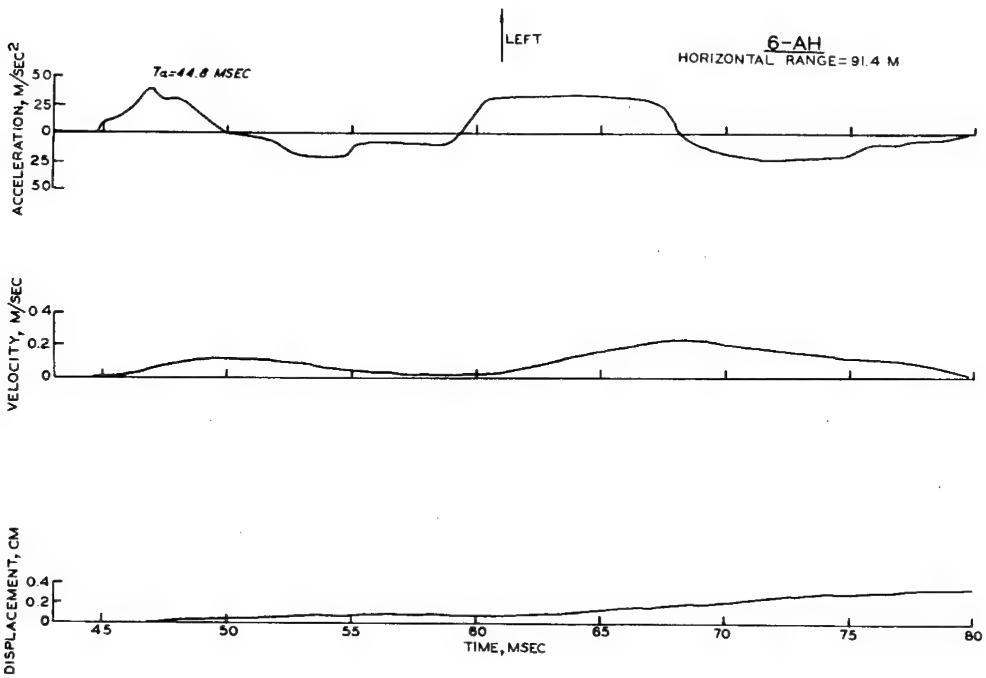


Figure 3.4 (4 of 7 pages)



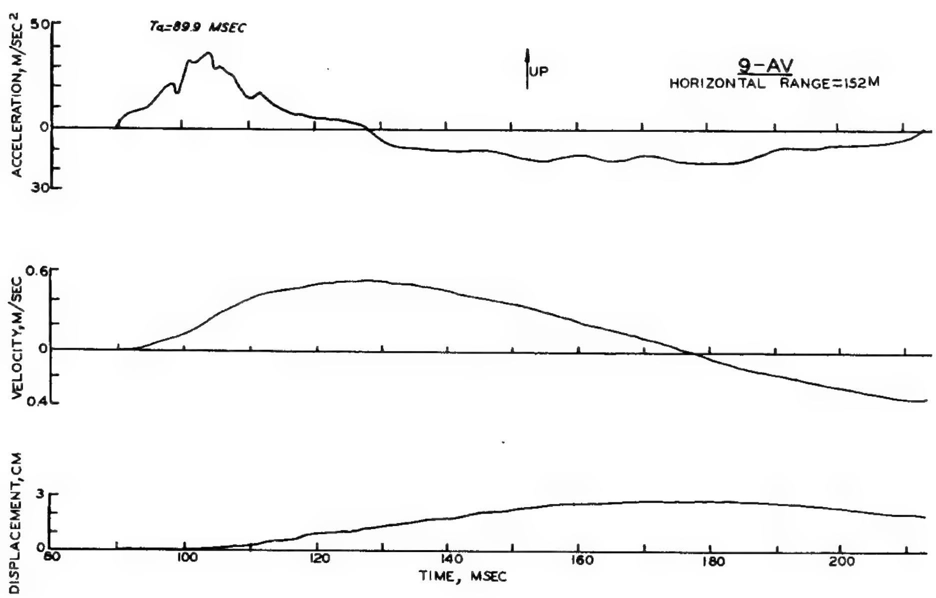
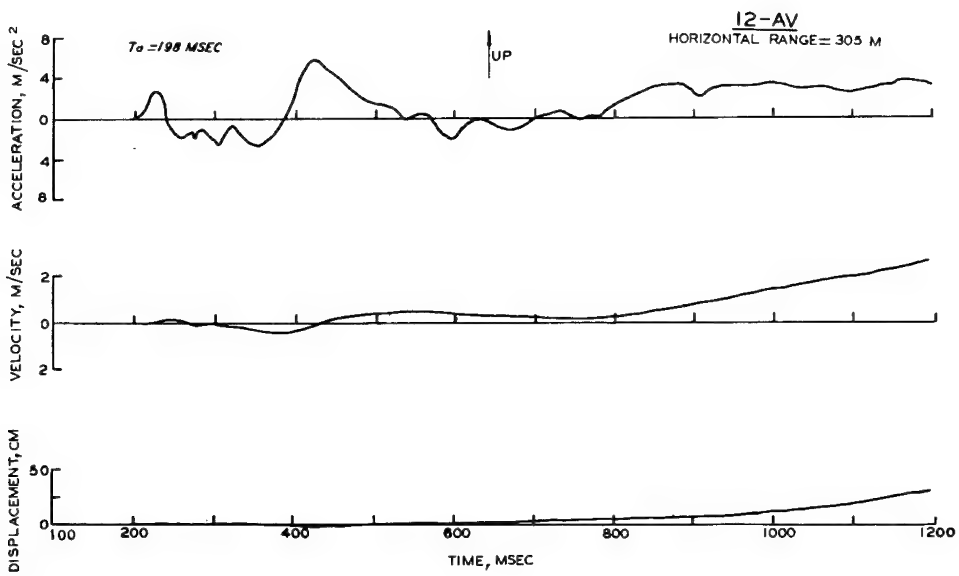


Figure 3.4 (5 of 7 pages)



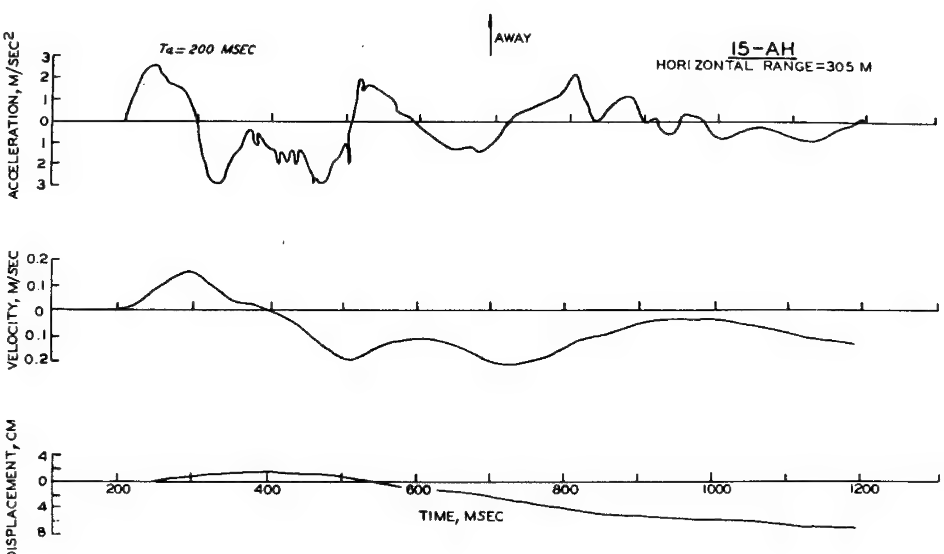


Figure 3.4 (6 of 7 pages)

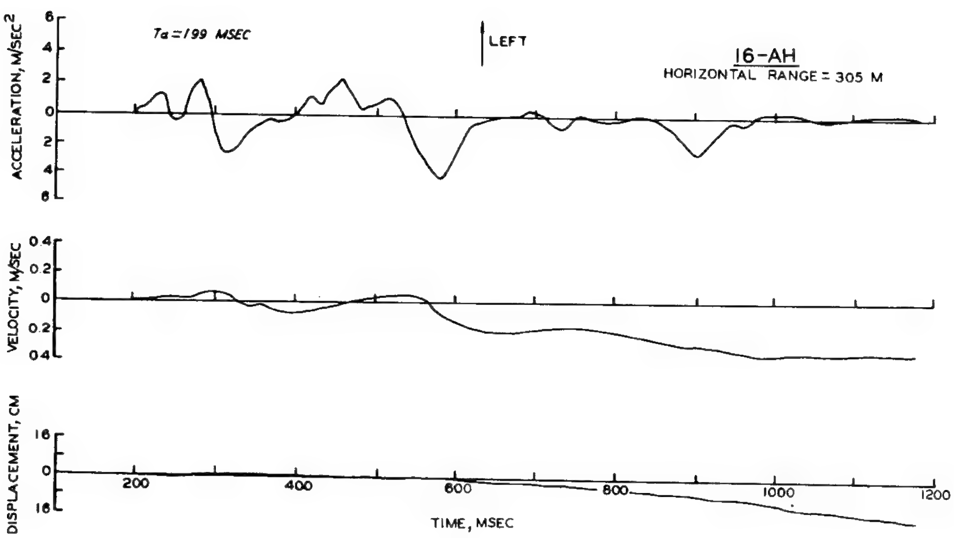


Figure 3.4 (7 of 7 pages)

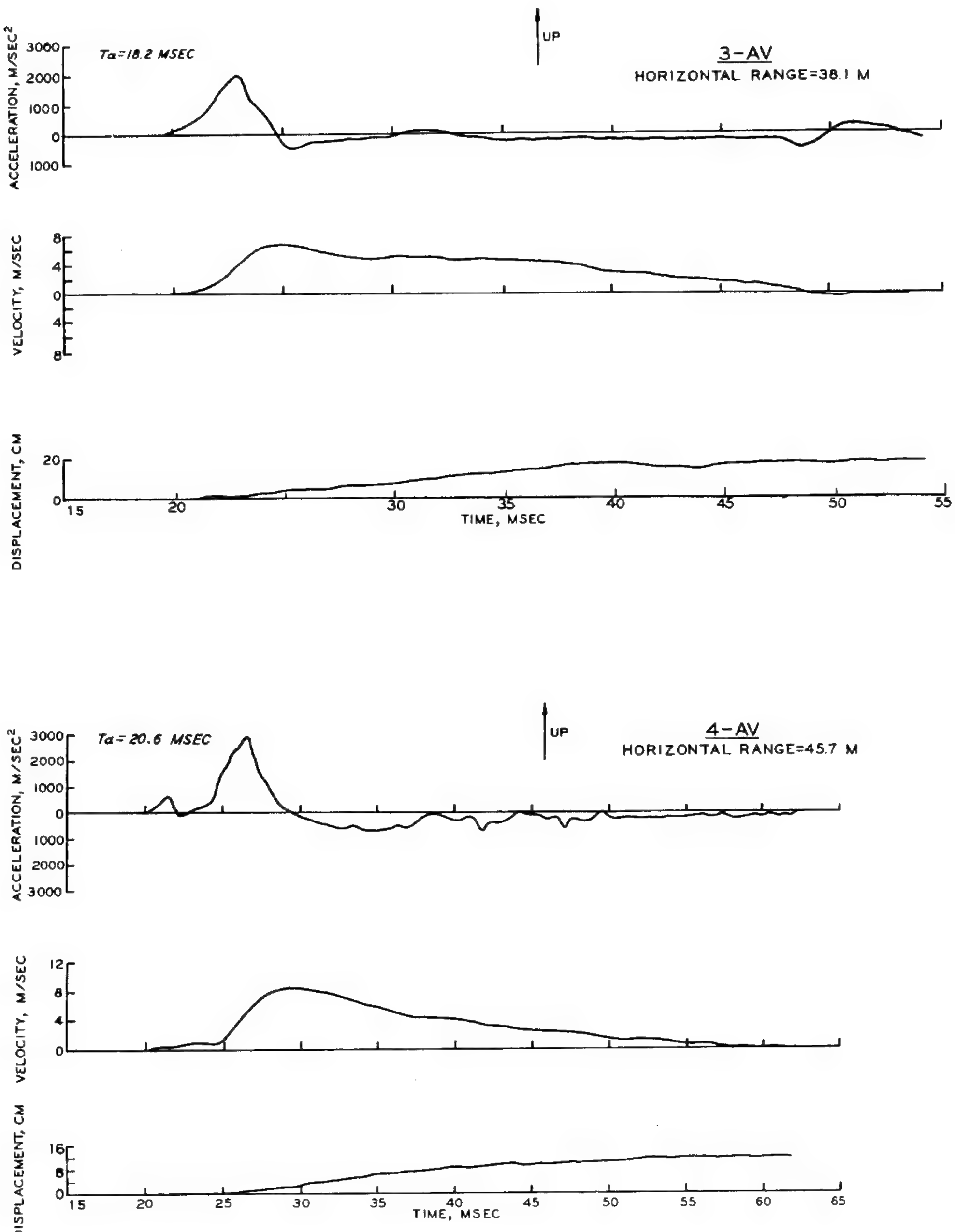
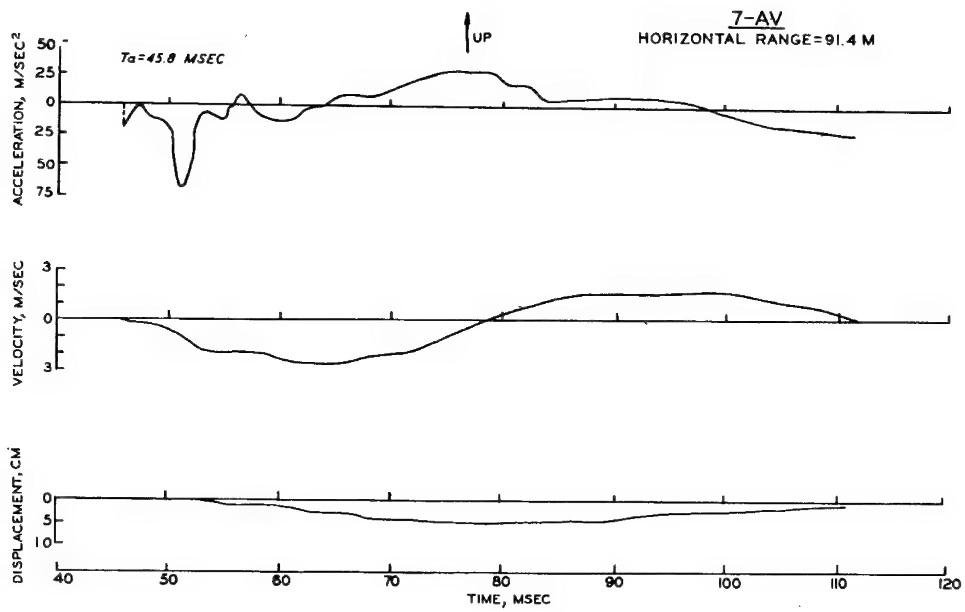
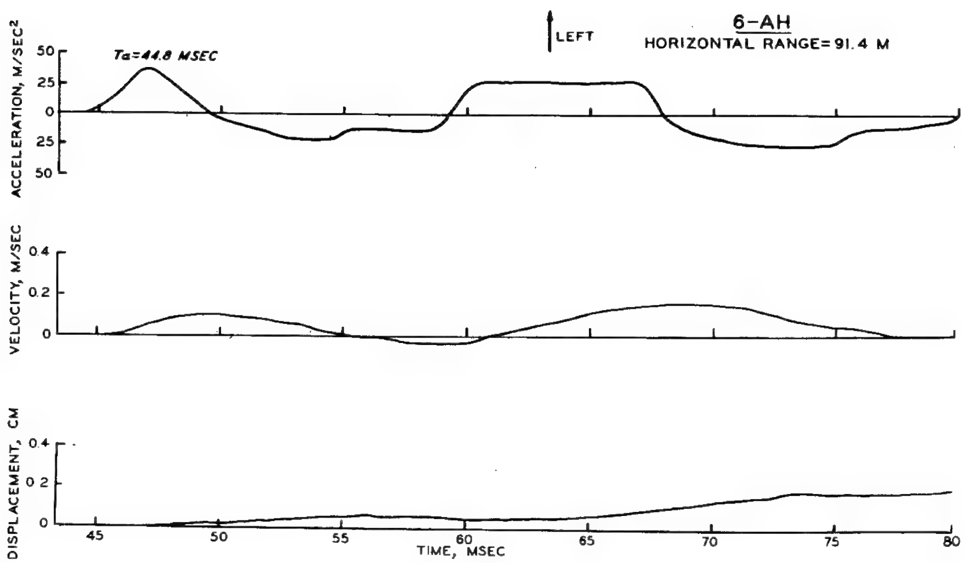


Figure 3.5 Corrected acceleration histories with twofold integrations (1 of 4 pages).





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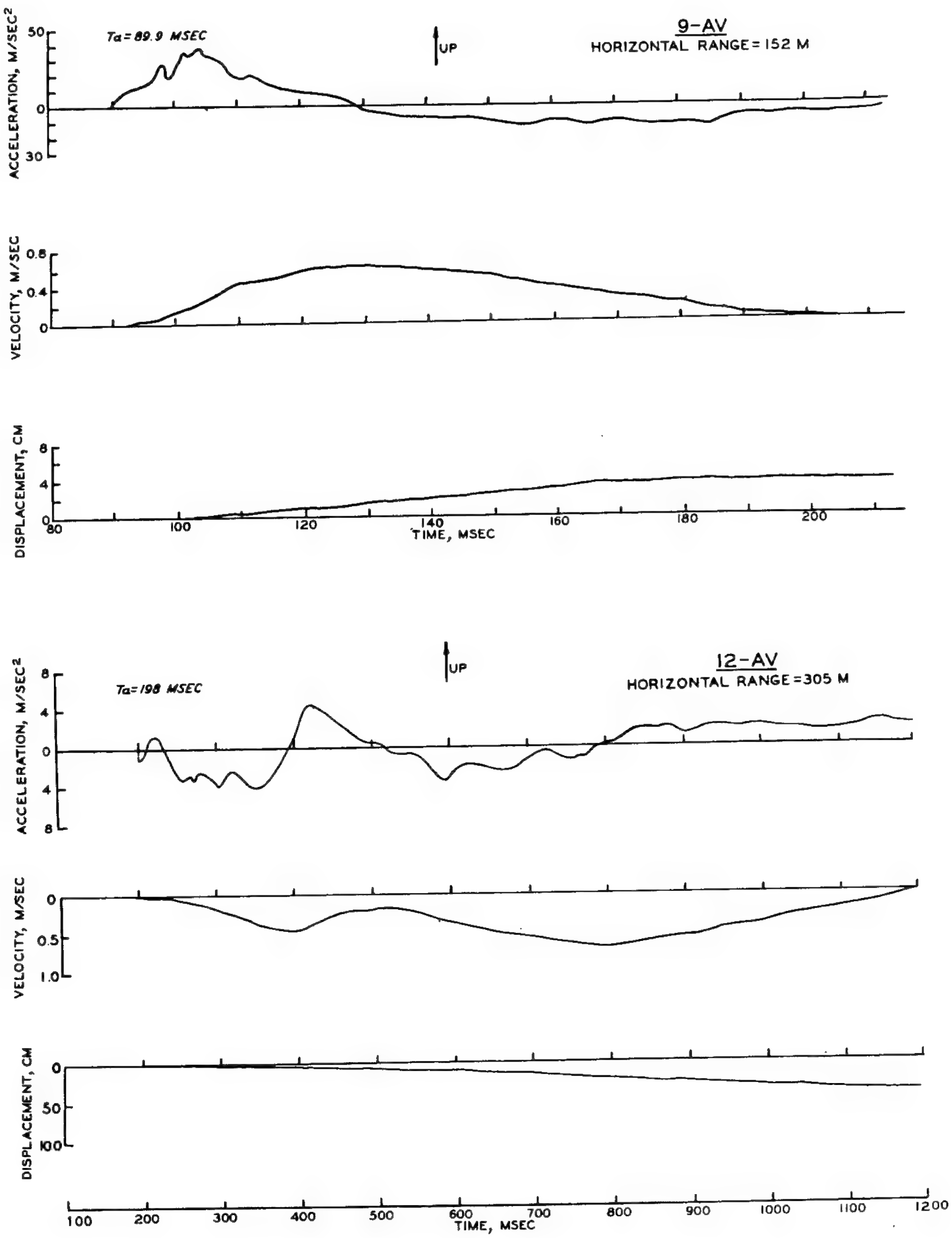

Figure 3.5 (3 of 4 pages)

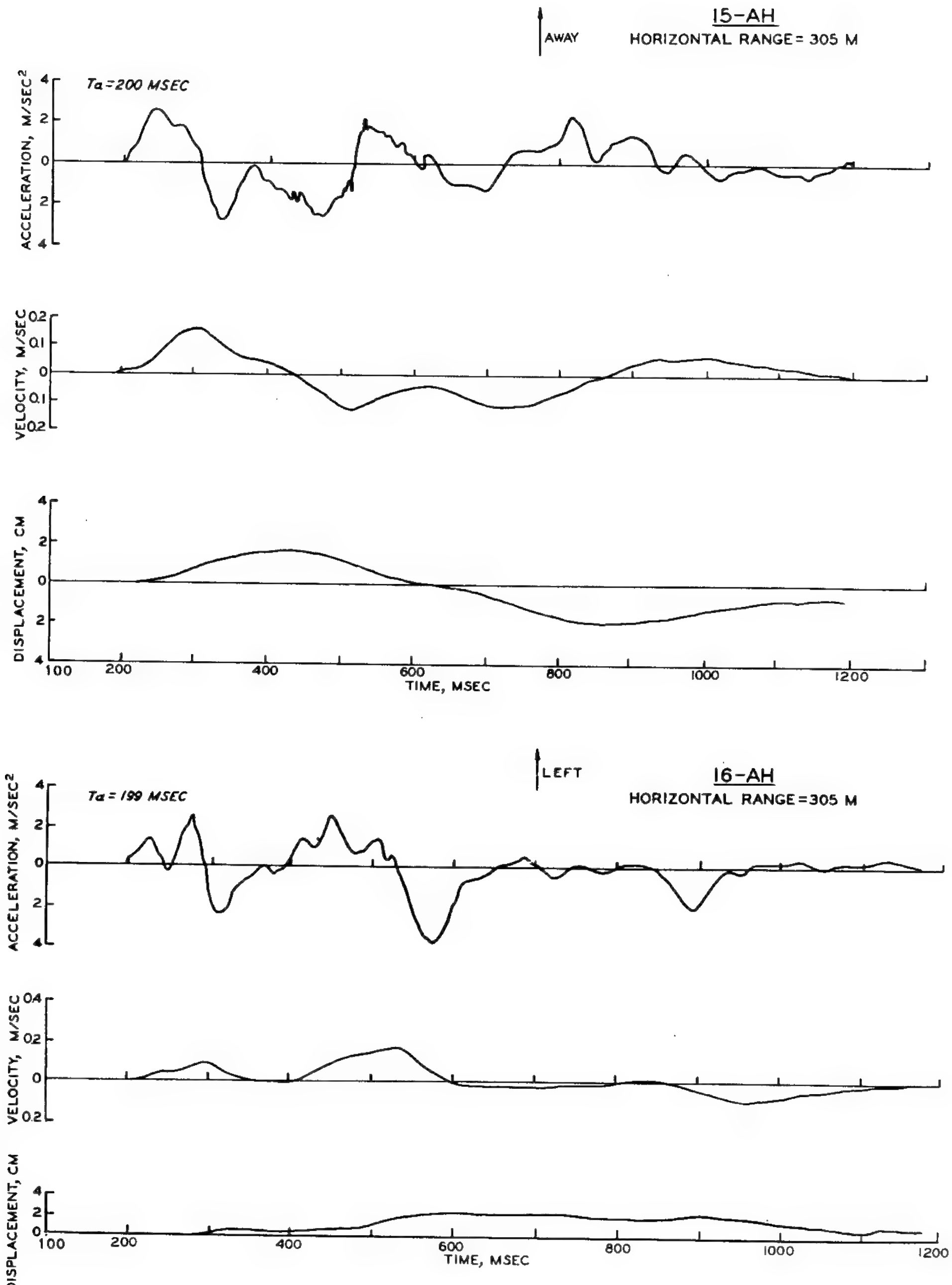

Figure 3.5 (4 of 4 pages)

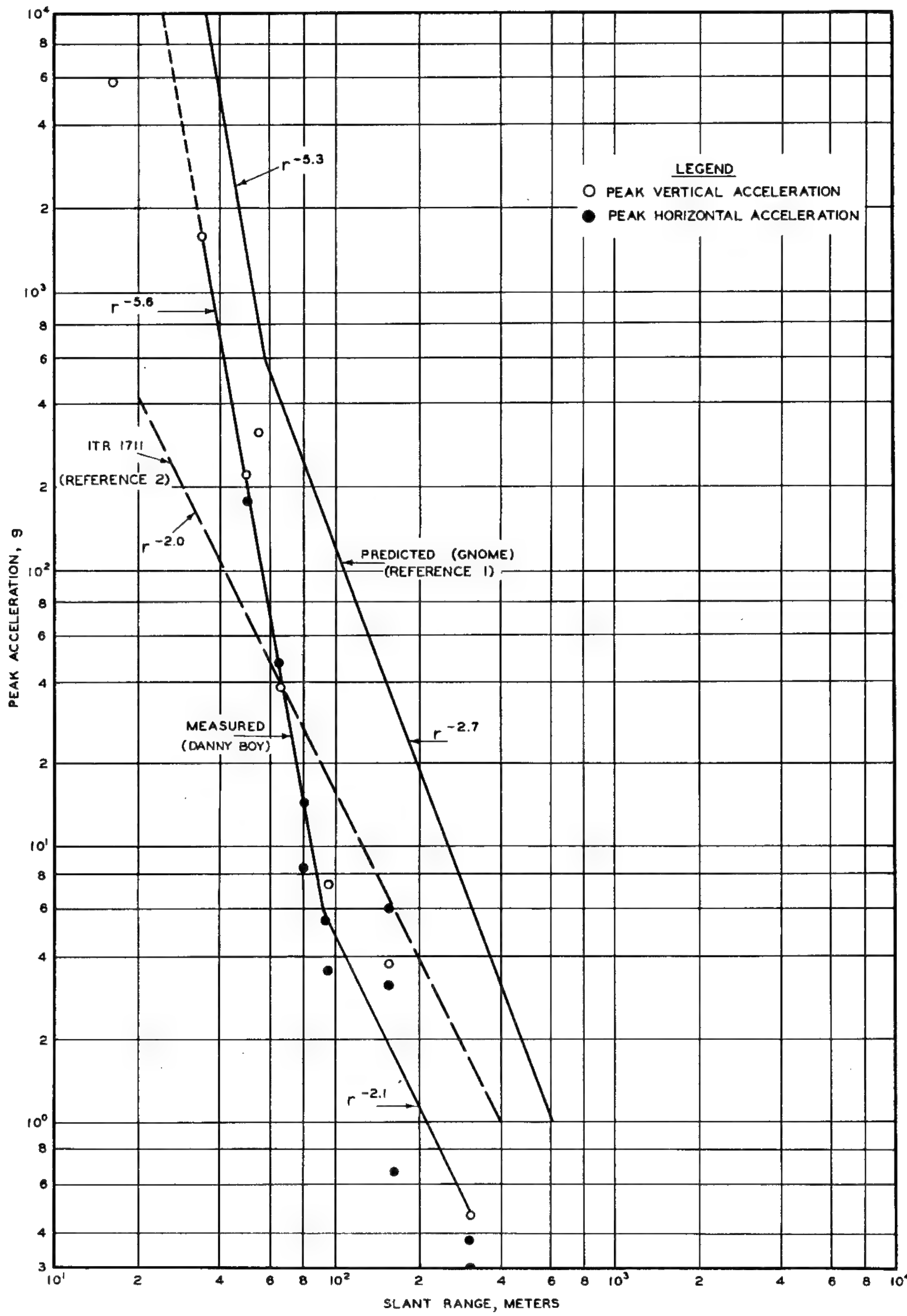

Figure 3.6 Peak acceleration as a function of distance.

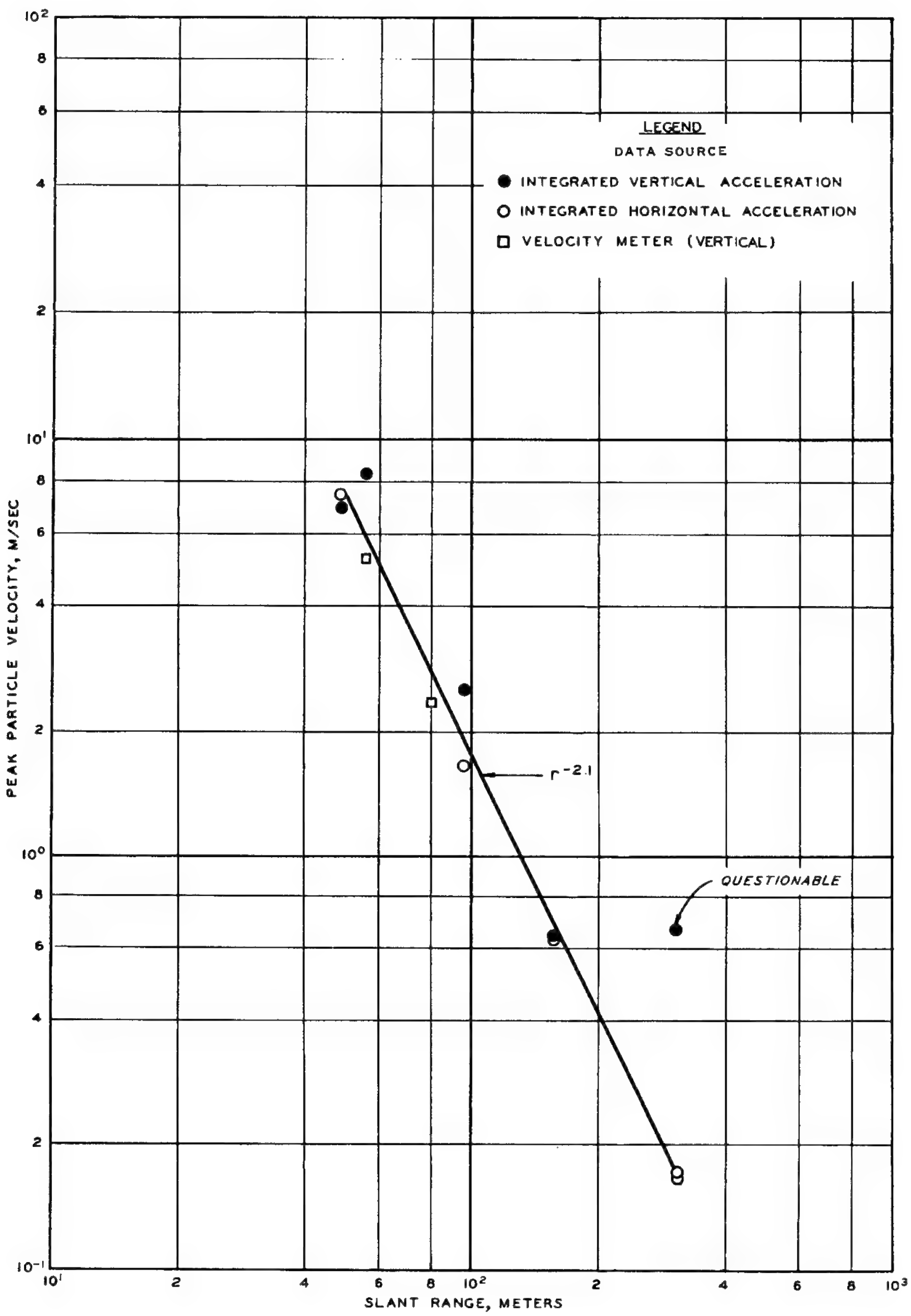

Figure 3.7 Peak particle velocity as a function of distance.

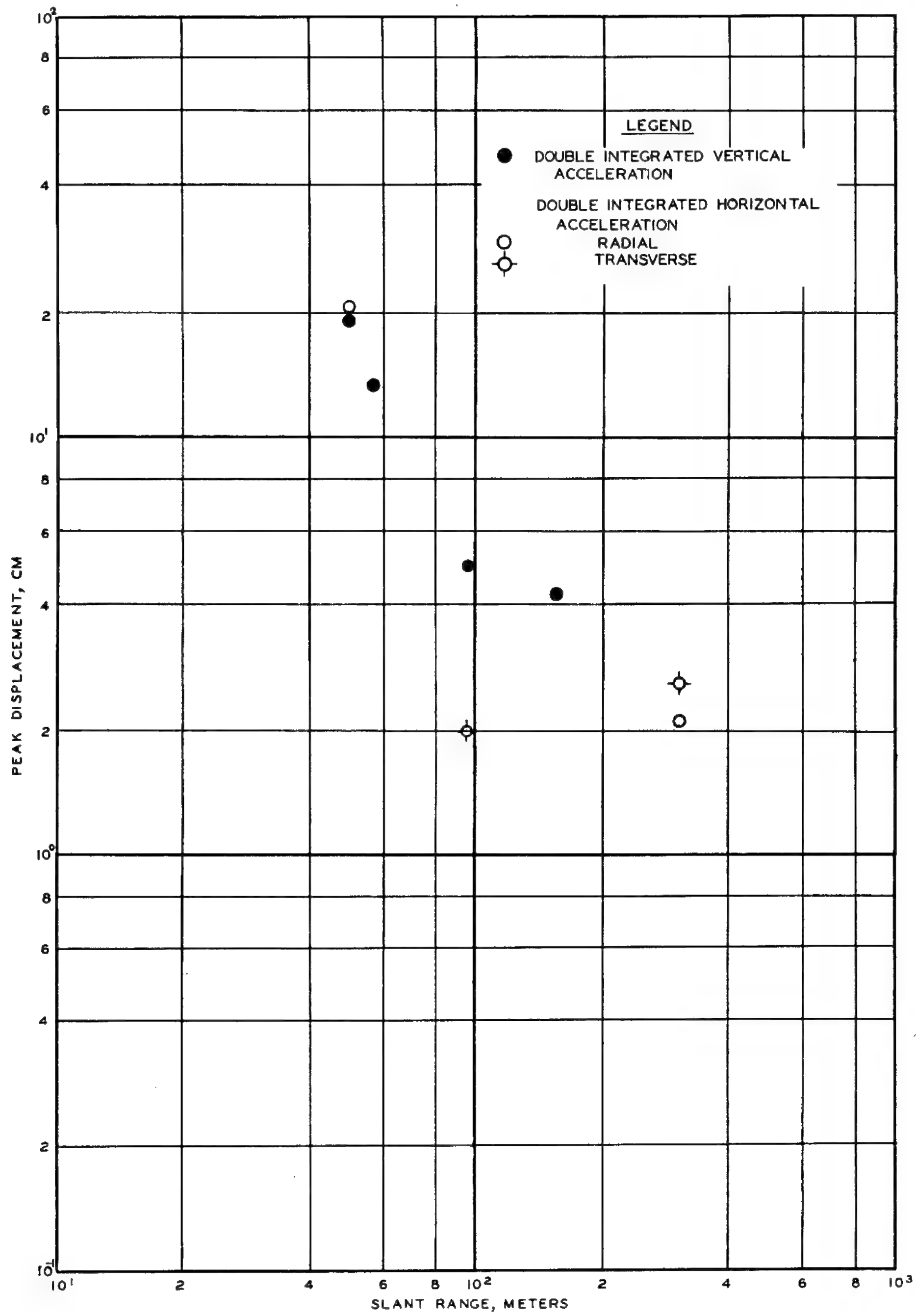

Figure 3.8 Peak displacement versus distance.

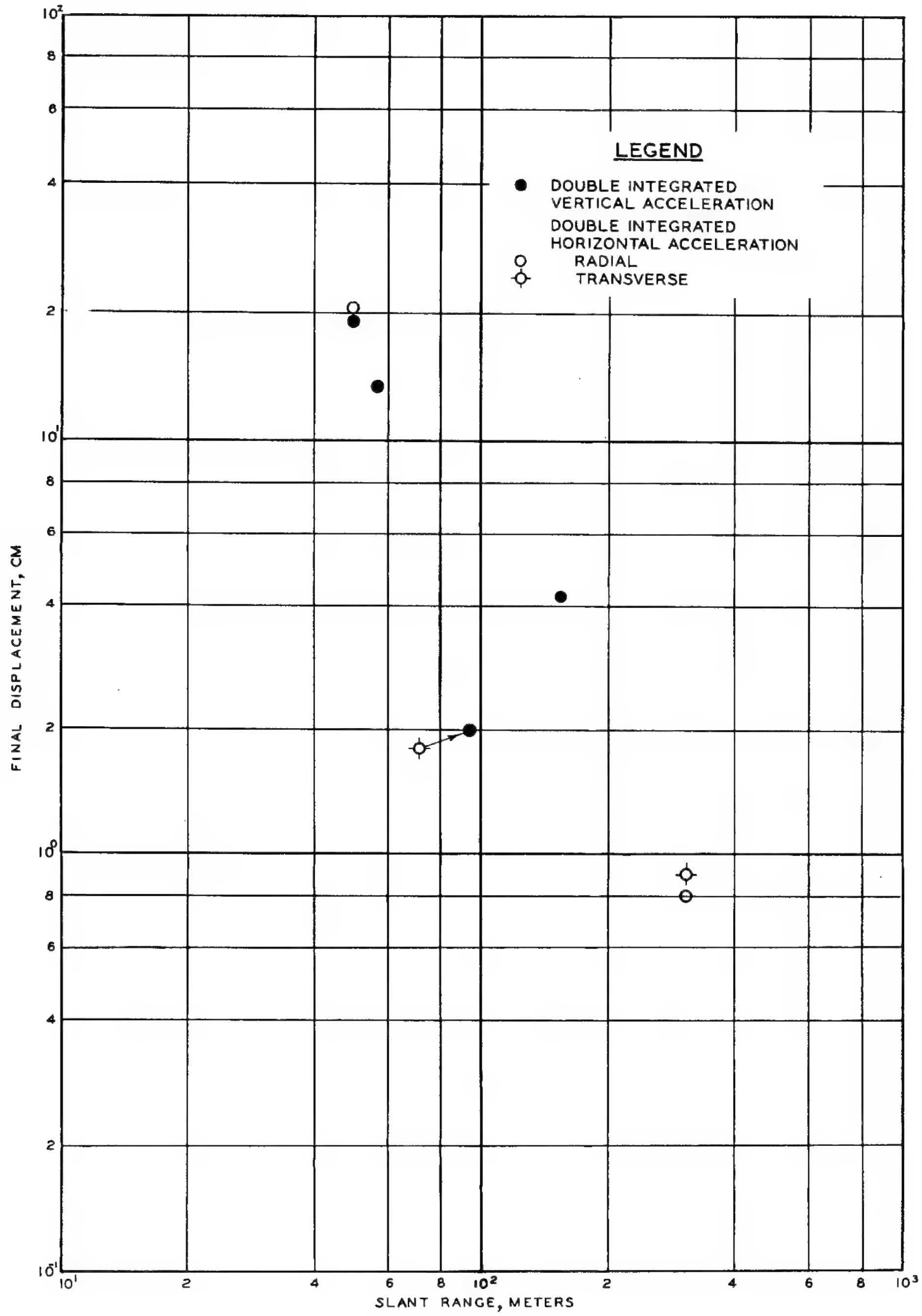

Figure 3.9 Final displacement versus distance.

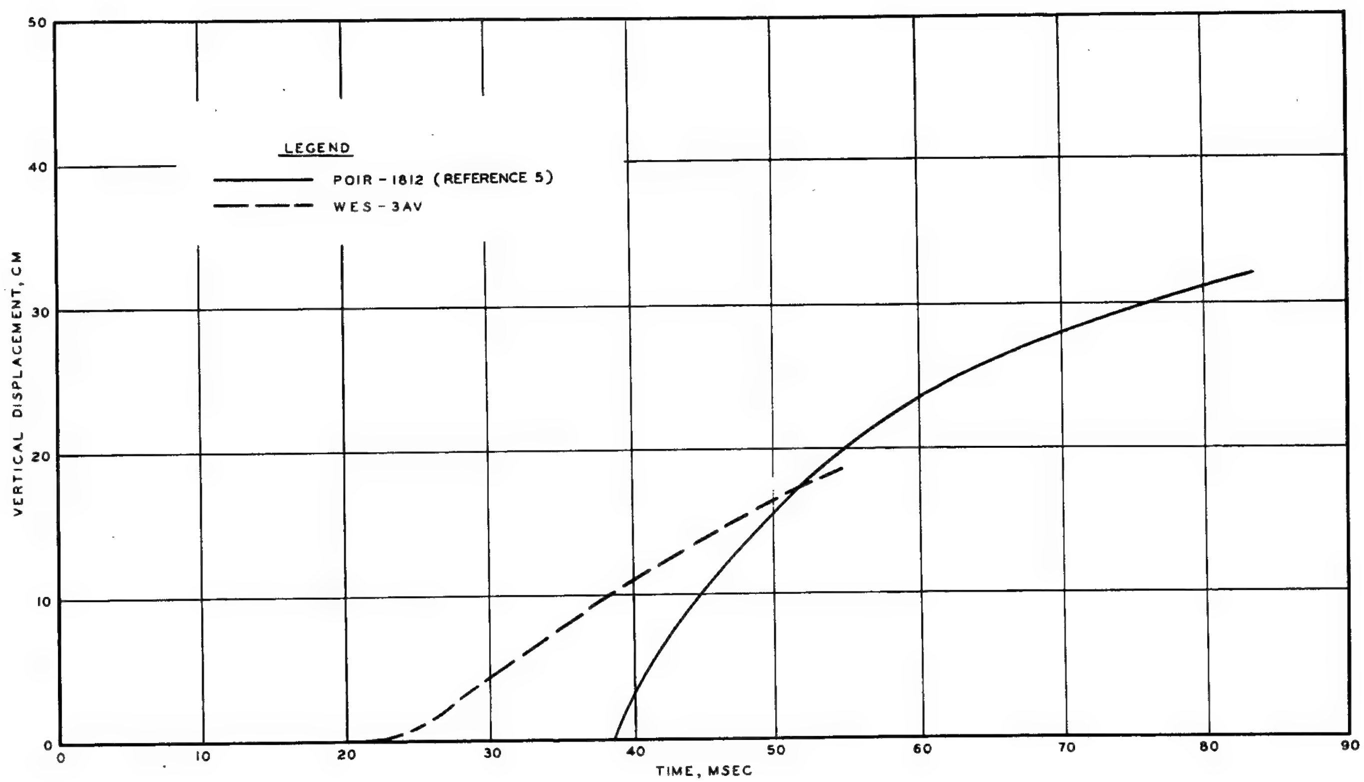

Figure 3.10 Comparison of WES and EG&G displacement data at 38.1 meters horizontal range.

CHAPTER 4

DISCUSSION

4.1 MEASUREMENTS

The small amplitudes of some of the traces made accurate scaling of the records quite difficult. For example, maximum deflection on some of the scaled traces was less than 0.1 inch. In some instances 100-g-capacity accelerometers were used to measure values much less than 10 g. Nevertheless, the peak values presented, except that of the gage closest to SZ, are considered reasonably accurate. The trace amplitudes from all gages closer than 55 meters and the 305-meter gages were large enough to scale with good accuracy.

The only measurement that appeared to suffer from lack of system high-frequency response was that from the deeply buried gage, 1-AV (slant range 15.6 meters), where frequency components of approximately 2,500 cps were evident (see Figure 3.4). This, of course, greatly exceeded the 600-cps capability of the System D, 3-kc/sec carrier amplifier. The apparently low value of peak acceleration from this gage was caused in part by this lack of high-frequency response. In

addition, the free-surface effect, which tends to double the free-field acceleration, would not apply to the buried gage. The data point obtained with this gage was not considered in plotting the curve in Figure 3.6 because of the low acceleration value.

The acceleration curve from the deeply buried accelerometer, 1-AV, is shown again in Figure 4.1, which shows the high-frequency components of the acceleration followed by what appeared to be cable failure. (The acceleration level remained at a fairly constant high level for an unrealistically long period of time.) The numerous sharp spikes of acceleration visible in Figure 4.1 might have been caused by crushing of the rock prior to the gross motion which resulted in cable failure. The special precautions taken to protect the cable (i.e. placing the cable inside a garden hose) apparently were successful in that measurements were made for an interval of 8 msec.

The vertical acceleration measurement obtained at 7.62 meters horizontal range (gage 2-AV) is considered to be a good measurement. The integrations of the gage 2-AV record were not corrected since the motion obviously did not stop prior to cable failure. No comparisons of the

displacement-time history have been made because of a lack of independent measurement.

A few acceleration measurements outside the crater, where low-amplitude traces were recorded, indicated that motion did not stop (as evidenced by a pulse of positive acceleration without a negative phase). This unrealistic behavior might have occurred because the low temperature undoubtedly increased the viscosity of the damping fluid of all instruments; thus, overdamping could have caused sufficient phase lag which, when coupled with very low-amplitude, initially positive motion, obscured the negative phase.

Peak accelerations were predicted assuming that the basalt at the test site was fairly uniform; however, seismic velocities computed from arrival times indicate that this is not the case. Borings in the area also revealed numerous voids, cinder pockets, etc.

Another factor that possibly contributed to the low acceleration values was the degree of coupling of the gages to the medium. It is conceivable that the masses of concrete in which the canisters were grouted could have been essentially "floating" in saturated soil. The response of this

type of system can be likened to a heavy mass-relatively soft spring system with a low natural frequency and a high degree of damping. Such a system would attenuate acceleration frequency components approaching or exceeding its natural frequency.

Results of measurements with the falling-core vertical velocity meters were somewhat disappointing. Although peak values were scaled from the initial part of the traces, the remainder of the records (from the two gages that sensed a significant velocity) was considered to be unreliable.

4.2 REDUCED DATA

The first integration of the acceleration histories, for a majority of the records, did not return quite to zero. The base-line correction, referred to in Section 3.2, was applied to records in which the total amount of required correction was less than five percent of the peak recorded acceleration. An exception to this was the record for gage 7-AV which had a 20 percent adjustment in peak value when the base-line shift was made.

The peak particle velocities, although exhibiting considerable scatter, resulted in a rather good grouping of

points that allowed plotting the relation between peak velocity and slant range (Figure 3.7).

Peak displacements also showed considerable scatter, and therefore no curve or fit was attempted. Nevertheless, the values plotted in Figure 3.8 do provide some idea of the approximate displacement amplitudes.

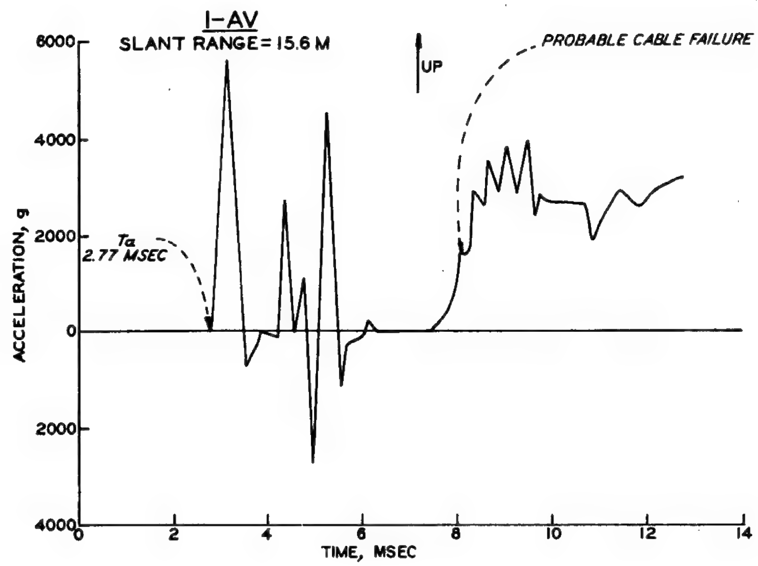

Figure 4.1 Early vertical-acceleration history in the crater region.

CHAPTER 5

CONCLUSIONS

5.1 INSTRUMENTATION EFFECTS

Overall instrumentation performance in Danny Boy Project 1.2 was satisfactory. Frequency response of the system was adequate with only one exception, i.e. at the deeply buried gage near the working point. The indicated peak acceleration at this location was approximately 5,700 g; the actual value was certainly much higher. It is not possible to estimate accurately the true maximum acceleration.

Gage-placement techniques might have had some effect on gage response. The degree of coupling to the basalt was uncertain because of the nature of the terrain at the ground surface.

5.2 MEASURED PARAMETERS

Signal levels were lower than expected, and thus produced several traces which were difficult to scale precisely. Nevertheless, an attempt was made to glean all possible information from the traces.

Seismic velocities ranged from 5.6 km/sec near the working point to 1.54 km/sec at a distance of 305 meters.

Peak acceleration attenuated approximately as slant range to the minus 5.6 power between 34 and 95 meters slant range, and as slant range to the minus 2.1 power between 95 and 300 meters slant range. Peak particle velocity attenuated as slant range to the minus 2.1 power between 50 and 306 meters slant range.

Peak displacements outside the crater ranged from about 20 cm at 38.1 meters horizontal range to 2 cm at 305 meters horizontal range. Because of the low amplitudes and inherent errors in twofold integrations, confidence in final displacement values is not good.

5.3 TERRAIN EFFECTS

The rapid decrease of seismic velocity with increasing distance from SZ is indicative that solid basalt does not prevail throughout the mesa in which the Danny Boy device was detonated. The highly vesicular nature of the mesa is probably responsible for the low-level motions obtained. The basalt mesa is not the ideal site for conducting ground-motion experiments in rock.

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2. Adams and others; "Summary Report of Strong Motion Measurements, Underground Nuclear Detonations"; Operation Hardtack Preliminary Report, ITR-1711, January 1960; Unclassified.

3. Swift, L. M.; "Development of an Earth Velocity Gage"; DASA-1191, October 1961; Stanford Research Institute, Menlo Park, Calif.; Unclassified.

4. Cheek, J. B., Jr.; "A GE-225 Computer Program for Numerical Integration with Automatic Method Selection"; Miscellaneous Paper No. 5-583, June 1963; U. S. Army Engineer Waterways Experiment Station, Vicksburg, Miss.; Unclassified.

5. Carder and others; "Surface Phenomena Photography"; Project Danny Boy Preliminary Report, ITR POIR/WT-1812, issued 15 February 1963; Edgerton, Germeshausen and Grier, Inc., Boston, Mass.; For Official Use Only.

TECHNICAL REPORTS SCHEDULED FOR ISSUANCE

BY AGENCIES PARTICIPATING IN PROJECT DANNY BOY

AGENCY	PROJECT NO.	REPORT NO.	SUBJECT OR TITLE
SC	1.1a*	1809	Long-Range Air Blast Measurements and Interpretations
SC	1.1b*	1810	Close-In Air Blast from a Nuclear Detonation in Basalt
WES	1.2**	1811	Earth Motion Measurements
EG&G	1.3**	1812	Surface Phenomena Photography
USC&GS	1.4/26.3/8.1**	1813	Seismic Effects from a Nuclear Cratering Experiment in Basalt
ARF	1.5**	1814	Throwout Study of an Underground Nuclear Detonation
WES	1.6**	1815	Mass Distribution Studies of Ejecta and Dust
LRL	1.9/26.2**	1816	Crater Studies
LRL	21.1***	1817	Distribution of Radioactivity from a Nuclear Cratering Experiment
UCLA	2.4***	1818	Some Radiological Observations and Characteristics of Fallout Debris from a Nuclear Cratering Experiment
NDL	2.5***	1819	On-Site Fallout from a Partially Contained Nuclear Burst in a Hard Medium
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SC	26.4**	1821	Results of the Sandia Seismic Net
ERDL	7.3	1822	Vegetation Studies
SRI	7.5	1823	Visual and Photographic On-Site Inspection
Boeing	1.10**	1824	Permanent Angular Displacement of Cylindrical Models

AGENCY	PROJECT NO.	REPORT NO.	SUBJECT OR TITLE
EG&G	**	1825	Timing and Firing
WES	**	1826	Design, Testing, and Field Pumping of Grout Mixtures
LRL	**	1827	Effects on Magnetic Properties of Basalt and Magnetite-Bearing Grout
USGS	**	1828	Geology of U18a Site, Buckboard Mesa, Nevada Test Site, Nye County, Nevada
USGS	**	1829	Geologic Effects of Explosions on Basalt of Buckboard Mesa, Nevada Test Site, Nye County, Nevada
USPHS	***	1830	Off-Site Radiological Safety
USWB	***	1831	Report of Weather and Radiation Transport
REECo	***	1832	On-Site Radiological Safety
LRL		1833	Summary Report of a Nuclear Cratering Experiment

Notes: Reports marked with one asterisk are to receive a basic distribution of Military Category 12, those with two asterisks Military Category 14, and those with three asterisks Military Category 26.

ABBREVIATIONS FOR TECHNICAL AGENCIES

ARA	Allied Research Associates Inc., Boston
ARF	Armour Research Foundation, Illinois Institute of Technology, Chicago 16
BOEING	The Boeing Company, Aero-Space Division, Seattle Attn: R. H. Carlson
EG&G	Edgerton, Germeshausen, and Grier, Inc., Boston, Las Vegas, and Santa Barbara
ERDL	U. S. Army Engineer Research & Development Laboratory, Fort Belvoir
LRL	Lawrence Radiation Laboratory, Livermore
NDL	U. S. Army Chemical Corps., Nuclear Defense Laboratory, Maryland
REECo	Reynolds Electrical and Engineering Co., Las Vegas
SC	Sandia Corporation, Albuquerque
SRI	Stanford Research Institute, Menlo Park
UCLA	University of California, Los Angeles
USC&GS	Coast and Geodetic Survey, Washington, D. C. and Las Vegas
USPHS	U. S. Public Health Service, Las Vegas
USWB	U. S. Weather Bureau, Las Vegas
WES	USA C of E Waterways Experiment Station, Vicksburg